THE RECONFIGURATION OF THE GLOBAL SUPPLY CHAINS OF CRITICAL MATERIALS:

BEHAVIOURS AND OUTCOMES IN THE COBALT SECTOR

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Declaration

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text.

It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text.

This dissertation is submitted according to the requirements of the Degree Committee of Land Economy. It does not exceed the regulation length including footnotes, references and appendices.

Jonathan Charles Michael Bedder

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Abstract

Why are contemporary raw material supply chains structured as they are? This dissertation explores what shapes the supply chains of 'critical materials', metals and minerals which are of high economic importance and are at risk of supply shortage. The research focusses on cobalt, a metal mined mostly in the Democratic Republic of the Congo (DRC) and consumed mostly in the production of lithium-ion batteries in Asia, which are used in portable electronics and electric vehicles. Focussing on the 2007 to 2017 period, the aim of this research is to determine how the cobalt supply chain is structured and organised, how its structure and organisation have evolved temporally, how firms and states have responded to cobalt's criticality, and how these responses have resulted in spatial and structural outcomes. The research thus aims to identify outcomes in the cobalt supply chain as well as the behaviours that have shaped those outcomes.

Research findings show that firms responded to cobalt's criticality through foreign direct investment and vertical integration, thus altering the structure and geographies of the cobalt supply chain. Chinese firms, in particular, invested heavily in Congolese cobalt assets in order to secure access to cobalt units for Chinese downstream consumers and brought more production processes within the boundaries of the firm to capture value. These firm-level developments took place in the context of state-level responses to cobalt's criticality. The research shows how a resource-holding state, the DRC, employed resource nationalist policies in order to capture value from the cobalt chain, while China, a resource-seeking state, created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value.

The research is grounded in the literature on resource scarcity, global supply chains, and global production networks (GPNs). Empirically, this dissertation provides the first detailed analysis of the cobalt supply chain within economic geography and demonstrates the potential of the GPN and related frameworks, as well as more traditional theories of the state, firm and international trade, to contribute to the debate on critical materials and explain the structure and formation of their complex global networks. Conceptually, the dissertation makes a small contribution the research on supply chains by examining how the factors that make materials critical (supply risk and economic importance) have brought about reconfigurations of supply chains, influenced the tactics of key actors, and shaped the geographies of resource extraction, production, and consumption.

Acknowledgements

Undertaking a part-time PhD has been a life-changing experience. What's more, life has changed immeasurably over the course of my time at Cambridge: I got a cat, I got engaged, I got married, I emigrated, I repatriated, I got a house, I got a dog, I got a son. I am enormously grateful for all of these experiences, as well as those that have come about directly as a result of this study of critical material supply chains. I have been fortunate enough to meet and discuss cobalt with interesting and engaging people across the world. My study of cobalt has taken me to the casinos of Las Vegas, to the skyscrapers of Tokyo, Shanghai and Hong Kong, and to the mines and refineries of Kolwezi and Lubumbashi. I am incredibly thankful and have a number of people to thank.

I was fortunate enough to have two supervisors at Cambridge. I am indebted to Professor Ron Martin and Professor Peter Tyler, who agreed to supervise a study of UK regional economic development that somehow evolved into an examination of the cobalt supply chain. Without their ideas, academic support, good humour, and constant encouragement, I would not have been able to chart the uncertain waters of part-time PhD study. Both have taught me a great deal about how to think and how to write. In return, I hope I have been able to teach them a little about cobalt.

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Nomenclature

Symbols

…	Not available
-	Nil

Abbreviations

M	Million
Bn	Billion
GWh	Gigawatt hours
t	Tonne
kt	Thousand tonnes
Mt	Million tonnes
tpy	Metric tonne per year
g	Gram
kg	Kilogramme
lb	Pound

Organisations and institutions

BGS	British Geological Survey
CI	Cobalt Institute
DOJ	US Department of Justice
EC	European Commission
OECD	Organisation for Economic Co-operation
SFO	UK Serious Fraud Office
UN	United Nations
USGS	United States Geological Survey
WCO	World Customs Organization
WTO	World Trade Organization

Others

EV	Electric Vehicle
FDI	Foreign Direct Investment
GCC	Global Commodity Chain
GVC	Global Value Chain
GPN	Global Production Network
ITN	International Trade Network
PGM	Platinum Group Metal
ROW	Rest of World
SOE	State-owned enterprise

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Part I

Part I of this dissertation introduces the reader to the research topic, outlines key research aims and objectives, explores relevant literature and related studies, and sets out the research methodology.

Chapter 1 introduces the research, provides background and context, and outlines previous research and gaps. It then sets out the core research aims and questions and introduces methodologies and data sources. The chapter concludes by outlining the research scope and with a summary of chapters.

Chapter 2 places the dissertation in context by providing an overview of the literature on materials availability, resource scarcity and critical materials. Thereafter, the characteristics of some critical materials sectors are explored. The chapter then moves to the selection of a case study raw material and 'cobalt' is chosen. A brief overview of the cobalt supply chain is then set out.

Chapter 3 reviews four bodies of theoretical literature relevant to this research. These are as follows: literature on international trade, literature on theories of the state, literature on theories of the firm, and literature on global chains and networks. This review of the literature serves the purpose of establishing what we know about *why* and *how* structural and spatial outcomes have occurred in contemporary supply chains. In each case, the literature is reviewed before being considered briefly in the context of the cobalt sector. The chapter finishes by outlining research questions and hypotheses.

Chapter 4 outlines the methodologies and data used in this research. The research employs a mixed method design. In Part II, Global Production Network (GPN) and International Trade Network (ITN) approaches are applied to the cobalt supply chain to outline its structure and organisation as well as its evolution over time. Part III uses case studies, a survey of cobalt-sector actors, and semi-structured interviews with similar parties to explore firm and state behaviours. Chapter 4 explains why these methods have been selected for the purposes of this research.

Figure 1 gives an overview of the structure of the thesis. Part I is highlighted in red.

Figure 1: Dissertation structure

Part	Part I - Research background				Part II - Outcomes in the cobalt sector		Part III - Responses in the cobalt sector		Part IV - Discussions and conclusions
Summary	Part I introduces the reader to the debates surrounding resource scarcity and critical materials and the cobalt sector. It then reviews the literature relevant to the research				Part II examines outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time		Part III is concerned with identifying some of the causal mechanisms that have shaped the observed outcomes detailed in Part II. It explores how cobalt's criticality has shaped the behaviours of firms and states		Part IV contains the research's conclusions
Chapter	C1. Introduction	C2. Resource scarcity, critical materials and the case of cobalt	C3. Theoretical debates on the nature and organisation of global supply chains	C4. Methodology	C5. A GPN approach to examining how the cobalt supply chain is structured and organised	C6. An ITN approach to charting the reconfiguration of the cobalt supply chain	C7. Firm responses to cobalt's criticality	C8. State responses to cobalt's criticality	C9. Conclusions and discussion
Summary	Introduces the research and outlines its background aims, key questions and structure	Introduces key literature on resource scarcity and critical materials before selecting a case study raw material (cobalt)	Introduces theories of international trade, theories of the firm and theories of global chains and networks relevant to the research	Discusses the use of GPN and ITN approaches for Part II and the use of case studies, a survey and semi-structured interviews for Part III	Uses a Global Production Network approach to show how the cobalt supply chain is structured and coordinated	Uses an International Trade Network approach to show how the geographies of the cobalt chain have evolved over time	Focussing on the upstream part of the sector in the DRC, the chapter looks at how firms have responded to cobalt's criticality exploring FDI and integration in particular	Focussing on the cobalt sector's major resource-holding state (the DRC) and resource-seeking state (China) this chapter explores how states have responded to cobalt's criticality	This chapter outlines key research conclusions, discusses the implications of the research findings, and outlines areas for additional study
Research questions addressed					RQ1: How is the cobalt supply chain structured and coordinated?	RQ2: How has the spatial structure of the cobalt sector changed over time?	RQ3: How have firms responded to supply risk and economic importance?	RQ4: How have states responded to supply risk and economic importance?	

Note: Red lines denote the current part

1. Introduction

1.1 Research background

This dissertation examines the changing patterns and underlying formation processes of critical material supply chains. It explores how these supply chains are structured and coordinated and also the causal mechanisms that have shaped observed spatial and structural outcomes. Since the turn of the century, there has been a considerable amount of research focused on critical materials – metals and minerals which are of high economic importance to a particular industry, sector or spatial area and are at risk of supply shortage (Bedder, 2015). The commercialisation of new technologies (mobile telephones, tablets, electric vehicles and alike) dependent on a range of exotic metals and minerals has made these materials increasingly vital to the global economy. At the same time, the ever-growing demand for these materials, resulting from the rapid industrialisation of China and other countries, has highlighted the possibility of material shortages to a global audience.

Little is known, however, about the complex supply chains of critical materials. Most research to date has only gone as far as to define critical materials by highlighting the high concentration of production of certain economically important metals and minerals in a small number of countries. Understanding what shapes the structure of their supply chains is important. Access to these materials, the key inputs for a range of technologies, is essential for global prosperity, and capturing value from natural resource endowments is highly important to economic development in some of the world's poorest regions. It is, therefore, vital to advance the debate on critical materials beyond classification and definition, and to make policymakers and industry participants aware of the complex networks that underpin critical material production and consumption, how these networks are formed and coordinated, and the various firm and non-firm actors involved.

Extractive sector production networks – the nexus of interconnected functions and operations through which goods and services are produced, distributed, and consumed – have, like many other networks, become both organisationally more complex and increasingly global in their geographic extent (Henderson et al., 2004, p.445). What is missing from the current policy debate over extractive industries, and the literature on critical materials, is a sense of the relational way in which production is organised via inter-firm and extra-firm networks that massively exceed the boundaries of the nation-state (Bridge, 2008, p.393).

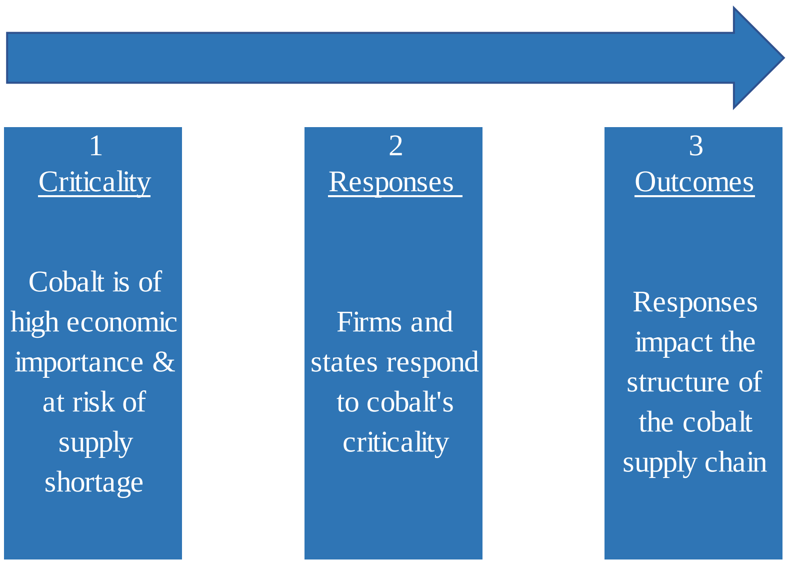
Recent advances in the conceptualisation and theorisation of global supply chains and production networks provide some of the tools with which to do this. Over the same period that the debate over critical materials has gained prominence, the emergence of global production and distribution systems has stimulated the rise of corresponding conceptual models to explain these developments. Global value chains (GVCs) and global production networks (GPNs) have been particularly useful as explanatory frameworks for understanding the global market engagement of firms, regions and nations (Neilson et al. 2014). These interrelated approaches explain geographical patterns of value creation, retention and capture in the global economy primarily through the conceptual architecture of chain governance and network dynamics – crucial theoretical shorthands for the ability of lead firms to coordinate the value-added activities of a multitude of economic actors (Neilson et al. 2014). The literature on global chains and networks has, however, for the most part, focused on the manufacturing and service sectors. To date, extractive industries have not been central to the GVC and GPN intellectual projects (see, however, Bridge, 2008; Bridge and Bradshaw, 2016; Dicken, 2015; Gibson and Warren, 2016; MacKinnon, 2013; Steen, and Underthun, 2011). Certainly, there have been no examinations of critical materials, with the aforementioned contributions focusing on energy (Bridge, 2008; Dicken, 2015; MacKinnon, 2013; Steen, and Underthun, 2011), base metals (Dicken, 2015; MacKinnon, 2013) and timber (Gibson and Warren, 2016).

This dissertation brings the literature on global supply chains and networks and the literature on critical materials together. It examines what we know about the theorisation of supply chains and how existing theoretical and conceptual frameworks are applicable to critical materials markets, casting new light on an under-researched area. It does so through the examination of one critical material in particular, cobalt, a metal for the most part mined in Central Africa and consumed in the production of batteries in Asia. Empirically, this dissertation provides the first systematic analysis within economic geography of the cobalt sector and demonstrates the potential of GPN and related frameworks, as well as more traditional theories of the state, firm and international trade, to contribute to the debate on critical materials such as cobalt and explain the structure and formation of their complex global networks.

Conceptually, the dissertation aims to advance the research on supply chains by examining how the factors that make materials critical (supply risk and economic importance) have brought about reconfigurations of supply chains, influenced the tactics of key actors, and shaped the geographies of resource extraction, production, and consumption. Figure 2 sets out a conceptual model showing the central thesis of this dissertation. It suggests that the factors that make cobalt critical (economic importance and supply risk) are in fact constitutive factors in the formation and structure of the cobalt supply chain.

Figure 2: Conceptual model

The central thesis that this model depicts is as follows: (1) Cobalt is a critical material because it is of economic importance and is at risk of supply shortage; (2) firms and states respond to cobalt's criticality through activities such as foreign direct investment and vertical integration; (3) these state and firm-level responses result in spatial and structural outcomes.



Source: Author's construction

Focussing on the 2007 to 2017 period, the aim of the research is to determine how the cobalt supply chain is structured and organised, how its structure and organisation have evolved over time, how firms and non-firm actors have responded to cobalt's criticality, and how these responses have resulted in spatial and structural outcomes. As such, the research aims to identify the behaviours that have shaped various outcomes in the cobalt supply chain, as well as the outcomes themselves. Thus, the research approach is shaped by a critical realist philosophy and has the goal of developing a better understanding of the causal mechanisms that have shaped observed outcomes (Sayer, 2000).

By meeting this research aim, the dissertation intends to further understanding of the origins and dynamics of global production networks and provide evidence to contribute towards the development of a more dynamic theory of global production networks that can better explain the emergence of different firm-specific activities, strategic network effects, and territorial outcomes (Yeung and Coe, 2015). Further, this research is intended to answer recent calls to explore how resource scarcity within GPNs evolves temporally; how firms operating in GPNs are able to adapt to resource scarcity (Gibson and Warren, 2016); and the role of states and other non-firm actors in contemporary production networks (Bridge, 2008; Horner, 2016). Additionally, the research seeks to further understanding of extractive sector and critical material markets, by examining the relational way in which production is organised via inter-firm and extra-firm networks (Bridge, 2008; Coe et al., 2008; Coe and Yeung, 2015).

My interest in this field stems from my employment at Roskill, an international metals and minerals research firm based in London, of which I am a Director. Since joining Roskill in 2012, I have researched the geology, production, trade, consumption, and price trends of numerous critical metals, including antimony, chromium, cobalt, gallium, manganese, niobium, tungsten and vanadium. However, this commercial research necessarily focuses only on the description of these metals' supply chains – quantifying supply, demand and trade and profiling the key actors involved. It is beyond the scope of the research reports and consultancy documents I produce at Roskill to explore *why* these supply chains are structured as they are, and what influences the behaviour of firm- and non-firm actors. As such, undertaking part-time PhD study at Cambridge, while continuing to work full time at Roskill, has allowed me to examine and better understand the causal mechanisms behind the market outcomes that I examine day to day.

1.2 Previous research and gaps

1.2.1 Critical materials

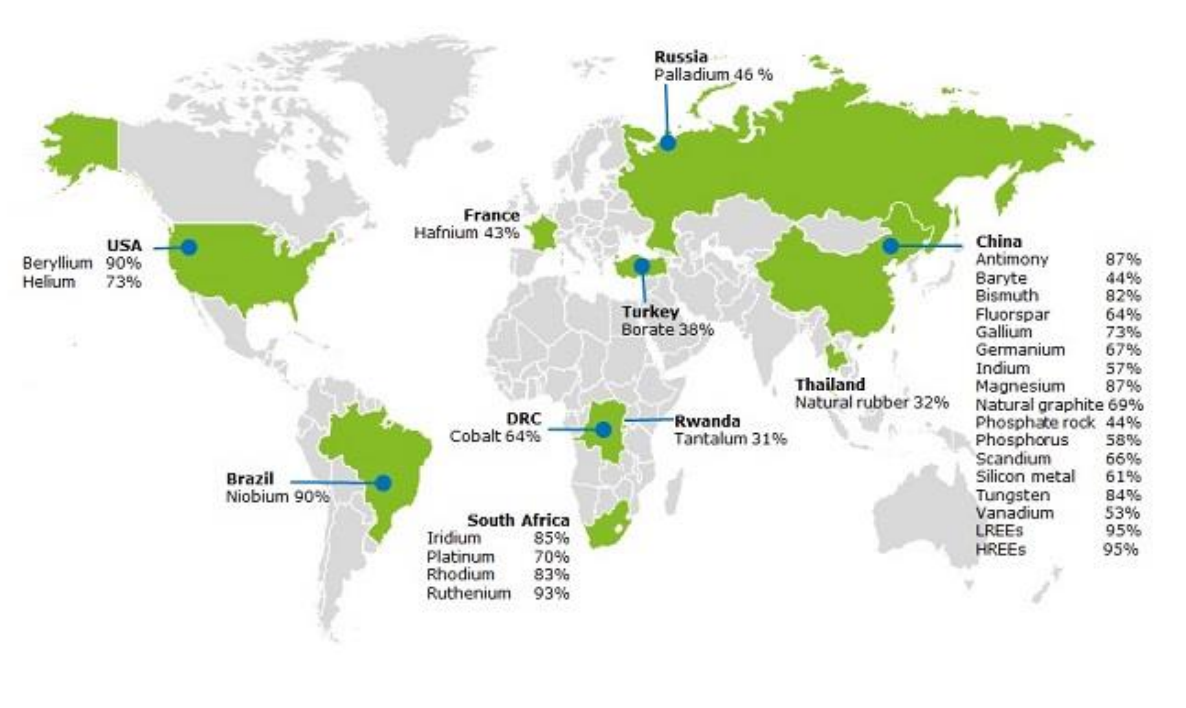
The literature on critical materials has its origins in more than two centuries of examination of mankind's dependence on certain resources. Literature on resource scarcity and growth has been shaped by context over time, evolving from early studies into the availability of food, into recent analyses of the materials most essential to modern industrial and technological production. This is because the extent to which a material is considered important or valuable is a socio-economic construct, which changes over time to reflect, among other factors, perceptions of current and future demand, the global political environment, and the state of technological development (Buijs et al., 2012).

The situation that has dominated discussions surrounding material availability since the turn of the century can be summarised as follows. In recent years, the commercialisation of new technologies such as laptops and smartphones has led to unprecedented demand for numerous esoteric metals and minerals. Growth in demand for these new technologies, and the raw materials within them, has also increased extraordinarily, as a result of rapid industrial growth and booming consumerism in countries like China. In many cases, increased demand has resulted in a sustained period of high prices as, among other reasons, producers operated close to capacity. Against this backdrop, concerns over the availability of certain materials have arisen, and have been compounded by the realisation that in several cases, production of these obscure metals and minerals only takes place in a small number of (sometimes geopolitically unstable) countries.

A wide number of metals and minerals have been considered as critical (see Figure 3 for the European Commission's 2017 list). Rare Earth Elements (REEs) are frequently cited as a critical material and serve as a useful introductory example. REEs are nearly all produced in China, which makes this group of elements potentially highly susceptible to supply risk according to several criticality studies (see for example EC, 2014; BGS 2015; EC, 2017). Further, they are used in a range of key industrial and technological applications, notably catalysts, magnets and batteries. Demand for REEs grew by 5.9%py between 2000 and 2008, dropped in 2009 with the global economic downturn and, then increased by 4%py to 2016 (Roskill, 2016b). In the decade to 2010, fluctuations in the prices for rare earth oxides were as much as +/-300%, with the main factors affecting price movements being changes in the world demand for telecommunications and electronic equipment coupled with a tendency on the part of Chinese suppliers to respond to demand from these sectors by increasing output, resulting in surpluses (Roskill, 2016b).

Figure 3: Critical raw materials as classified by the European Commission in 2017

The metals and minerals classed as critical by the European Commission in 2017. Percentages refer to the high proportion of production in certain states. For example, 90% of niobium is produced in Brazil.



Source: EC (2017)

Articles and studies on critical materials have become commonplace since the turn of the century. More papers were published on critical materials between 2001 and 2013 than were published on the subject in the preceding half-century and the publication of articles on critical materials has increased at a much faster rate than those on related materials availability subjects such as resource assessment, photovoltaic materials and recycling (Speirs et al., 2013). Several national and regional governments have conducted criticality studies and developed raw materials strategies (see for example NRC, 2008). Such studies either scrutinise the economy (global, regional, national or sub-national) or a specific sector or technology from a criticality perspective. There have also been industry-led studies into critical materials (see for example Cullbrand and Magnusson, 2012; Duclos et al., 2010) which focus on the criticality of materials that form part of the supply chain, and numerous material-focussed studies have also been conducted (see for example Harper et al., 2014; Harper et al., 2015; Nuss et al., 2014; Panousi et al., 2015).

Many contributions have taken the form of multi-commodity assessments which seek to apply a wide range of measures to metals and minerals, allowing raw material availability to be quantitatively examined and compared. Many have taken a criticality matrix approach which considers candidate materials in light of their economic importance or impact of supply restriction on the one hand, and the possibility of supply risk on the other (see for example, Buchert et al., 2009; DOE, 2011; Duclos et al., 2010; EC, 2010; EC, 2014; EC 2017; NRC 2008).

A core motivation for this dissertation is the contention that critical materials research has reached an impasse in recent years. While there have been a plethora of studies focussed on critical material definition and classification, there have been few that have sought to explore the dynamics that underpin these sectors, the causal mechanisms that shape the behaviours of the key actors involved, and the spatial and structural outcomes that occur. This represents an important research gap. It is important to advance the debate on critical materials beyond classification and definition, and to make policymakers and industry participants aware of the complex networks that underpin critical material production and consumption, how these networks are formed and coordinated, and the various firm and non-firm actors involved. Only in doing so, can regional-, national-, industry- and firm-level strategies for ensuring raw material access be formulated and applied.

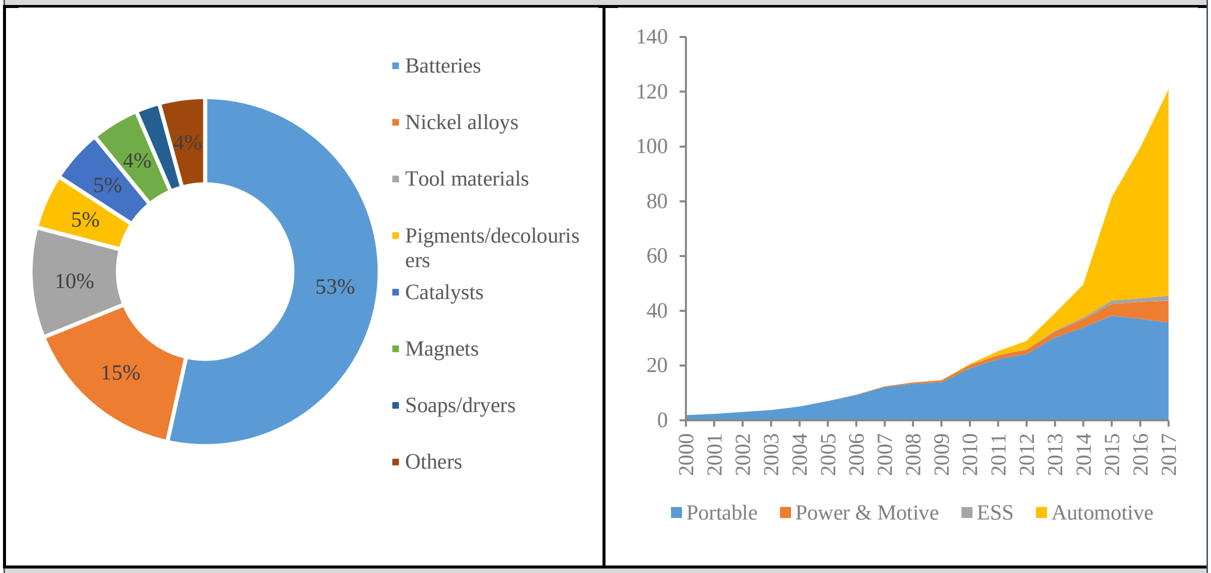
1.2.2 The case of cobalt

In part as a result of similarities between methodologies, numerous raw materials have been classified as critical in several studies. Cobalt is one such metal (see for example BGS, 2015; Coulomb et al., 2015; EC, 2014; EC, 2017) and has been selected as the case study raw material for this dissertation (see chapter 2.4). Cobalt has been utilised by for at least 2,600 years, dating back to Ancient Egypt providing blue pigments for glassware and ceramics (CI, 2017). Today, cobalt is recognised as an important technology-enabling metal where energy storage, high-temperature resilience, hardness, process efficiency and environmental benefits are required (CI, 2017).

To use the nomenclature of the literature on critical materials, cobalt's 'economic importance' is a result of its use in a wide variety of important industrial and technological applications. Cobalt is widely consumed in nickel alloys, tools, catalysts, pigments and magnets (Figure 4). Most importantly, cobalt is used in the vast majority of cathodes in lithium-ion batteries, a type of rechargeable battery. Demand for lithium-ion batteries has seen considerable growth since 2000, underpinned by growth in their use in portable electronics (Figure 4). While demand for lithium-ion batteries in such applications has stagnated in recent years, it is generally accepted that lithium-ion battery demand is set to increase substantially as electric vehicles continue to gain market share. UBS, a bank, predicts electric vehicles will make up 14% of global car sales by 2025, up from 1% today (The Economist, 2017). Such growth will see cobalt demand grow considerably, meaning that cobalt's economic importance is set to endure, if not increase, over the medium term.

Figure 4: World: Consumption refined cobalt and lithium-ion batteries

Cobalt is mostly consumed in batteries and principally in the cathodes of lithium-ion batteries. Consumption of these batteries has increased sharply since 2000, underpinned by demand for lithium-ion technologies in portable electronics and, latterly, electric vehicles.



Source: Roskill (2018)

Note: Left-hand side shows consumption of cobalt 2017 (%) and right-hand side shows consumption of lithium-ion batteries, 2000 to 2017 (GWh)

'Supply risk' with regard to cobalt stems not from physical scarcity but from the uneven spread of the metal across national territories. Cobalt ranks 32nd in terms of abundance of chemicals in the earth's crust, making it more abundant than some seemingly ubiquitous metals (CI, 2017). However, it is only found in economic concentrations in a small number of countries and is almost always mined as a by-product of copper or nickel.[1] About 50% of global cobalt reserves are found in the Democratic Republic of Congo (DRC) (USGS, 2016) with approximately 70% of the world's cobalt feedstock being sourced from this country (Roskill, 2018). It is also mined in large quantities in Zambia, Canada, Cuba, Australia, Madagascar and Russia.

The production chain for cobalt, like that of many critical materials, is complex. Material mined is typically upgraded into an intermediate cobalt product (the most common is cobalt hydroxide) which is in turn further processed into a variety of refined cobalt chemicals or metal. In some cases, the entire process takes place in one location, and within the boundaries of just one firm. Generally, though, the supply chain is global in reach with cobalt bought and sold in its various forms and traded internationally by firms specialising in just one or two stages of production. Cobalt firms range from small producers and consumers to some of the biggest trans-national corporations (TNCs) in the world, some of which have vertically integrated cobalt production facilities spread across multiple jurisdictions. Producers include mining giants like Glencore and BHP Billiton and consumers include major technology companies such as Apple, LG, and Panasonic. The vast majority of the cobalt mined in the DRC is shipped to China, where the bulk of the world's refined cobalt chemicals and metal are produced. These materials are then further consumed in the production of batteries, alloys, and magnets, much of which, today, takes place in Asia.

Cobalt serves as a highly suitable case study for several reasons. First, mine production is highly concentrated in one, politically unstable country, the DRC. As a result, cobalt is typical of a material of which there are enduring concerns over supply risk. Second, cobalt is consumed in a wide range of economically important applications. Third, and as a result of its use in batteries and other key applications, cobalt has seen considerable consumption growth in recent years and further, demand is forecast to increase considerably over the coming decade.

Cobalt also represents an ideal case study raw material given that this dissertation is concerned with complex global supply chains and production networks. While mined principally in Africa, cobalt is

[1] Over 90% of cobalt is mined as a by-product of copper or nickel. In Morocco, cobalt is mined as a primary product. Some cobalt is produced as a by-product of Platinum Group Metal (PGM) mining in South Africa. Very small quantities are produced as by-products of other metals.

largely refined in Asia, particularly China, Europe and North America meaning that the cobalt supply chain is global in reach. This makes cobalt an ideal case study with which to explore theories and concepts more typically applied to global manufacturing and service sectors.

By focussing on the cobalt sector in depth, this research also addresses some cobalt-sector research gaps. By going beyond the more descriptive studies of the sector provided by industry consultants and public bodies (see for example USGS, 2016) this dissertation contributes significantly to the available empirical evidence on the sector and helps further understanding of how material availability has shaped the supply chain (Alonso et al. 2011).

1.2.3 Global chains and networks

While it necessarily includes considerable firm- and state-level analysis, this research is theoretically grounded in the literature on supply chains and production networks. Contemporary globalisation is characterised by worldwide and boundary-crossing flows of people, information, and materials (Holton, 2008). A rich body of literature has emerged that attempts to offer an understanding of the processes that underpin these flows; drive global production, consumption and trade, and shape transnational spatial relationships. This is for good reason. The world and its actors are connected by an increasingly dense and complex web of overlapping and intertwined links, both physical and virtual, which have allowed us to take the principle of comparative advantage to levels that Ricardo could never have imagined (Goldin and Mariathasan, 2014).

The interdependence bought about by globalisation has created a number of economic advantages. International trade has accelerated, underpinned by the liberalisation of capital markets and a decline in protectionism, and fostered by the numerous international institutions established in the wake of World War II such as the International Monetary Fund (IMF), the World Trade Organization (WTO) and the World Bank, (Soubbotina and Sheram, 2000). In combination with technological advances that have enhanced communication and transportation, liberalisation has facilitated unprecedented economic growth in a number of economies, most notably China. As a result of globalisation, many states have benefitted from global sourcing and access to larger markets for their products, helping firms to drive costs down and helping them to realise the benefits of comparative advantage. Further, greater inward investment and higher levels of employment and consumption have been achieved as a result of buying and selling in a global marketplace.

There have also been disadvantages. Those countries that have been slow to integrate with the world economy have seen trade decline and development stall (Soubbotina and Sheram, 2000). Financial globalisation and foreign direct investment have been associated with an increase in inequality (IMF, 2007). In addition, the rise of large multi-national corporations (MNCs) has, in some cases, created monopsonies of labour, barriers to entry and challenging conditions for smaller firms globally, while some have argued that the rise of MNCs has led to the fast depletion of some non-renewable natural resources and the prioritisation of profit maximisation ahead of the development needs of poorer countries (Shah et al. 2012).

Supply chains and production networks have been the focus of considerable governmental, academic and industry attention in recent years. A voluminous literature has emerged on international trade networks, global commodity chains, global value chains and global production networks. Contributors to this field have been motivated by a desire to theorise, conceptualise and empirically examine supply chains, which are now spread across the globe and are increasingly complex. The emergence of China and other recently developed and developing economies has substantially altered the structure of the global economy, necessitating new approaches and theories to explain the ever-changing dynamics of global production and trade. There are an ever-growing number of actors and agents involved in the production process, including institutions, governments, and firms, spread across multiple jurisdictions. It has been argued that empirically, there is now no doubt that global production networks and global value chains are the most critical organisational platforms through which production in primary, manufacturing and service sectors is coordinated and organised on a global basis (Yeung and Coe, 2015). The literature on supply chains has, however, for the most part, focused on the manufacturing and service sectors. There have been relatively few studies on primary sector supply chains and no known studies on critical materials. This dissertation addresses this research gap through its focus on the cobalt sector.

The focus on primary sector supply chains and production networks places this research within an ever-relevant field of inquiry. The primary sector, that is the sector that makes use of natural resources such as agriculture, forestry, fishing and mining, remains essential in the globalised age. The adequate supply of raw materials is vital to the global economy. To an extent, the primary sector's importance can be quantified by conventional metrics. For example, according to the World Bank (2019), total natural resource rents averaged 2.7% of global GDP in between 1970 and 2017 and a much higher proportion of GDP in low-income states (11%) and fragile and conflict-affected areas (18%). In the DRC, a mineral-rich but fragile state from where most of the world's cobalt is sourced, such rents amounted to 32% of GDP in 2017. For states like the DRC, maximising ground rents from their natural endowments is important for development and growth given the relative importance of the primary sector to the country's total goods and services production.

Unlike manufacturing and service sector firms, which can theoretically be located anywhere, the primary sector is a special case, given its utilisation of physically embedded natural resources. Societies are dependent on access to resources which are spread irregularly across the planet meaning that they are not always readily available to those that require them. Climatic conditions, *inter alia*, make the conditions for optimising agriculture and forestry better in some parts of the world than others. Modern technologies have, to an extent, helped to widen the geographies of these primary sectors. However, mineral resources are geographically fixed and, given the heterogeneous geology of the planet, spread unevenly across national boundaries. This creates a special set of conditions against which the theoretical frameworks used to understand global supply chains can be tested, enabling evaluation of their usefulness for analysis of fuels, metals and minerals supply chains given their geographically constrained mineral resource inputs.

1.3 Research aims and questions

Focussing on the 2007 to 2017 period, the aim of this research is to determine how the cobalt supply chain is structured and organised, how its structure and organisation have evolved temporally and geographically, how firms and states have responded to cobalt's criticality (supply risk and demand growth), and how these responses have resulted in spatial and structural outcomes. The research aims to identify the behaviours that have shaped various outcomes in the cobalt supply chain, as well as the outcomes themselves. Put another way, it seeks to identify the causal mechanisms that have shaped observed outcomes. To meet this research aim, four research questions are posed.

RQ1. How is the cobalt supply chain structured and coordinated?

RQ2. How has the spatial structure of the cobalt sector changed over time?

RQ3. How have firms responded to supply risk and economic importance?

RQ4. How have states responded to supply risk and economic importance?

Based on the literature review and the conceptual framework set out above, several hypotheses have been developed and are detailed in Chapter 3.5. These hypotheses represent basic suppositions of *how* the cobalt sector ought to be structured, and which factors *ought* to have shaped its development, based on the literature.

1.4 Methods

This research employs a mixed-method design. Desk-based research and quantitative analysis are combined with qualitative research. For the most part, qualitative research builds directly on the results of desk-based and quantitative research. As such, the quantitative results are explained in more detail through the qualitative findings. It is intended that the combination of quantitative and qualitative methods measure overlapping but also different facets of the cobalt sector, yielding an enriched, elaborated understanding of cobalt sector dynamics (Greene et al., 1989). As noted above, the research sets out ‘outcomes’ before looking to understand the behaviours that have shaped those outcomes. Outcomes are explored in Part II and behaviours in Part III of the dissertation.

The term quantitative research is used to refer to a type of research that is explaining phenomena by collecting numerical data that are analysed using mathematically based methods (Creswell, 1994). The term qualitative research is used in its most basic sense to refer to empirical research where the data are not in the form of numbers (Punch, 1998) and which occurs in a natural setting enabling the researcher to develop a level of detail from high involvement in the actual experiences (Creswell, 1994).

In Part II, quantitative research is used to understand outcomes in the cobalt sector. Chapter 5 utilises secondary data on cobalt production and consumption. The chapter focusses on the 2007-2017 period, using available data on cobalt supply and demand, based on a wide range of industry reports, company reports, trade journals, and government publications. Chapter 6, examines the International Trade Network (ITN) for cobalt units, to show the evolution of import-export relationships between all countries engaged in cobalt trade over time. This involves the examination of international trade flows using graph-theoretic structures where countries (vertices, or nodes) are linked by edges or links (representing the value/volume of a trade) to show import-export relationships between countries (see for example Bhattacharya et al., 2007; Benedictis & Tajoli, 2011; Abbate et al., 2012). The specifics of the methodologies and data employed in Part II are introduced in Chapter 4.

In Part III, to understand behaviours, the research applies a mixture of quantitative and qualitative approaches. The cobalt sector is secretive and opaque. In many cases, information regarding things as diverse as ownership, capacity, production, processing techniques, trade, consumption, supply chain partnerships and even product is deemed commercially sensitive. While some information can be gathered from desk-based research and from published sources, such as the reports of publicly listed companies, much has to be gleaned through personal contacts and relationships. This research is concerned with the behaviours of firm- and non-firm actors. It is certainly not possible to understand behaviours from publicly available information.

In light of the nature of the cobalt sector and the focus of this research, a combination of case studies, questionnaire survey and semi-structured personal interviews have been used. A survey has the advantage of gathering data for a representative group of cobalt sectors actors to provide generalisable statements and data about firm responses to cobalt's criticality. Further, a survey has the advantage of being a productive use of research time (Llieva et al. 2002) while reaching a wide geographic spread of respondents (Garton et al. 1999).

These data are built upon using semi-structured interviews. Unlike other forms of empirical research, interviews, or what Gordon Clark labelled close dialogues, rely upon the intimacy or closeness of researchers to industry respondents, a level of personal commitment quite at odds with the conventional notions of scientific disassociation and objectivity (Clark, 1998). Over the course of this part-time PhD research, and throughout my employment at Roskill, I have worked to develop close relationships with a wide number of cobalt-sector actors. Some I have known for seven years. Through discussion of the cobalt sector with these contacts, this research is able to draw upon unique insights from industry actors shared as a result of, in many cases, long-standing personal and professional relationships.

Interviews have a number of advantages. They provide an opportunity to evaluate the validity of the respondent's answers by observing non-verbal indicators, which is particularly useful when discussing sensitive issues (Smith, 1975). They also ensure that the respondent is unable to receive assistance from others while formulating a response (Bailey 1987). Semi-structured interviews specifically allow depth to be achieved by providing the opportunity on the part of the interviewer to probe and expand the interviewee's responses and thus providing room for negotiation, discussion, and expansion of the interviewee's responses (Hitchcock and Hughes, 1989). In these interviews, the interviewer is in control of the process of obtaining information from the interviewee but is free to follow new leads as they arise (Bernard, 1988). Thus, while a structured interview is based on a fixed list of questions and allows little opportunity for digression, a semi-structured interview is open, allowing new ideas to be brought up during the interview as a result of what the interviewee says.

Semi-structured interviews allow for new ideas on the nature of the cobalt market to emerge as they facilitate the broadening of discussion points based on key areas of knowledge held by each interviewee in order to develop insights into the research issues (Denscombe, 2007). Further, they allow for respondents to provide information on the cobalt sector that might not have been gleaned had interview topics been confined solely to those chosen by the interviewer. The use of semi-structured interviews enabled the capture of original responses that were used to construct insightful and original research narratives.

Case studies are also used alongside the findings from semi-structured interviews. A case study is a systematic inquiry into an event or a set of related events which aims to describe and explain the phenomenon of interest (Bromley, 1990). Put another way, a case study is an empirical inquiry about a contemporary phenomenon, set within its real-world context (Yin, 2009). A case study approach is particularly useful when the researcher is trying to uncover a relationship between a phenomenon and the context in which it is occurring (Gray, 2004).

1.5 Scope and summary of chapters

The dissertation is set out in four parts. Part I introduces the reader to the research, to the debates surrounding resource scarcity and critical materials, and to the cobalt sector. It then reviews the literature relevant to the research. Part II is concerned with observed outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time. Part III is concerned with identifying some of the causal mechanisms that have shaped the observed outcomes detailed in Part II. It explores how cobalt's criticality (notions of supply risk and economic importance) have shaped the behaviours of firms and states. Part IV contains the research's conclusions.

Part I

This chapter (chapter 1) introduces the research, providing initial context and background to the study, outlining previous research and gaps, and introducing the research aims, questions and methods.

Chapter 2 places the dissertation in context by providing a historical overview of the literature on materials availability, resource scarcity and critical materials. Thereafter, the characteristics of some critical materials sectors are explored. The chapter then moves to the selection of case study material and cobalt is chosen. A brief overview of the cobalt sector and supply chain is then set out.

Chapter 3 reviews four bodies of theoretical literature relevant to this research. These are as follows: literature on international trade, literature on theories related to extractive sector states, literature on theories of the firm, and literature on global chains and networks. This review of the literature serves the purpose of establishing what we know about why and how structural and spatial outcomes have occurred in contemporary supply chains. In each case, the literature is reviewed before being considered in light of the cobalt sector.

Chapter 4 outlines the methodologies used in Part II and Part III. In Part II, the research applies Global Production Network (GPN) and International Trade Network (ITN) approaches to analysis of the cobalt sector. Part III utilises a combination of desk-based research, a survey and semi-structured interviews.

Part II

Chapter 5 presents a global production network for cobalt and explores the structure of the supply chain. In doing so, it provides the first application of a GPN approach to a critical material market and uses tools from the GPN analytical toolkit to explain the cobalt supply chain's formation and structure. The chapter addresses RQ1: How is the cobalt supply chain structured and coordinated?

Chapter 6 addresses RQ2: How has the spatial structure of the cobalt sector changed over time? The chapter presents the first known international trade network (ITN) analysis of a critical material in order to uncover stylised facts about changes to the cobalt supply chain over time. This represents a novel approach, as such analysis is usually at the aggregate or commodity-class level. Several statistical approaches, typical of ITN studies, show changes in network density and strength over the period of analysis.

Part III

Chapter 7 explores RQ3: How have firms responded to perceived resource scarcity and demand growth? In doing so it seeks to explore firm behaviours and responses to cobalt's criticality. Using information gathered from desk-based research, case studies, a cobalt-sector survey and semi-structured interviews, the chapter then explores firm behaviours and strategies across the supply chain, testing hypotheses derived from the literature review.

Chapter 8 concerns itself with RQ4: How have states responded to perceived resource scarcity and demand growth? Using similar approaches to chapter 7, the chapter explores two hypotheses through a focus on two case-study states, one resource-holding (the DRC) and one resource-seeking (China).

Part IV

Chapter 9 contains the dissertation's conclusions. The chapter outlines the research's novel contributions and revisits the research questions, hypotheses and findings. It also discusses the implications of the research findings for policymakers concerned with critical materials, considers the research's limitations, and outlines areas for future study.

The schematic below is found at the beginning of each of the four Parts of this dissertation but has also been included here, in the summary of chapters, for convenience.

Figure 5: Dissertation structure

Part	Part I - Research background				Part II - Outcomes in the cobalt sector		Part III - Responses in the cobalt sector		Part IV - Discussions and conclusions
Summary	Part I introduces the reader to the debates surrounding resource scarcity and critical materials and the cobalt sector. It then reviews the literature relevant to the research				Part II examines outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time		Part III is concerned with identifying some of the causal mechanisms that have shaped the observed outcomes detailed in Part II. It explores how cobalt's criticality has shaped the behaviours of firms and states		Part IV contains the research's conclusions
Chapter	C1. Introduction	C2. Resource scarcity, critical materials and the case of cobalt	C3. Theoretical debates on the nature and organisation of global supply chains	C4. Methodology	C5. A GPN approach to examining how the cobalt supply chain is structured and organised	C6. An ITN approach to charting the reconfiguration of the cobalt supply chain	C7. Firm responses to cobalt's criticality	C8. State responses to cobalt's criticality	C9. Conclusions and discussion
Summary	Introduces the research and outlines its background aims, key questions and structure	Introduces key literature on resource scarcity and critical materials before selecting a case study raw material (cobalt)	Introduces theories of international trade, theories of the firm and theories of global chains and networks relevant to the research	Discusses the use of GPN and ITN approaches for Part II and the use of case studies, a survey and semi-structured interviews for Part III	Uses a Global Production Network approach to show how the cobalt supply chain is structured and coordinated	Uses an International Trade Network approach to show how the geographies of the cobalt chain have evolved over time	Focussing on the upstream part of the sector in the DRC, the chapter looks at how firms have responded to cobalt's criticality exploring FDI and integration in particular	Focussing on the cobalt sector's major resource-holding state (the DRC) and resource-seeking state (China) this chapter explores how states have responded to cobalt's criticality	This chapter outlines key research conclusions, discusses the implications of the research findings, and outlines areas for additional study
Research questions addressed					RQ1: How is the cobalt supply chain structured and coordinated?	RQ2: How has the spatial structure of the cobalt sector changed over time?	RQ3: How have firms responded to supply risk and economic importance?	RQ4: How have states responded to supply risk and economic importance?	

Note: Red lines denote the current part

2. Resource scarcity, critical materials and the case of cobalt

This chapter places the dissertation in context by providing an historical overview of the literature on materials availability, resource scarcity and critical materials. Thereafter, the characteristics of modern critical materials sectors are explored, and a case study metal is selected. Some general information on this metal, and previous studies related to its criticality, are then set out.

There is a wealth of literature that explores the implications, and potential limitations, of mankind's dependence on certain resources. This is of no surprise, as societies are dependent on access to resources that are not only finite but also spread unevenly across the planet meaning that they are not always readily available to those that require them.

As societies have evolved, and wants and needs have transformed, so too has the focus of the literature on materials availability and resource dependence changed to reflect the most pertinent materials availability concerns of the day. The literature on resource scarcity has been shaped by context over time, evolving from early studies into the availability of food, into recent analyses of the materials most critical to modern industrial and technological production. Materials which are deemed as critical today were not always deemed to be so.

The following sub-chapter outlines a chronology of the literature on resource scarcity, but it is first important to note three points about resource scarcity as a concept.

The first is that resource scarcity is a socially constructed phenomenon. While many of the planet's resources are technically finite, the extent to which a material is considered important or valuable is a socio-economic construct, which changes over time to reflect, among other factors, perceptions of current and future demand, the global political environment, and the state of technological development (Buijs et al., 2012). As perceptions about a materials importance or value change, so too do perceptions of scarcity change over time. As set out in the subsequent analysis, raw material criticality is today defined by classifying materials as economically important and at risk of supply shortage. There are no tangible, physical characteristics that make a material critical. This label, and concerns about scarcity more broadly, are socially generated.

As scarcity is constructed, and shaped by context – by economic, political, and social factors – conceptualising it is complex. Mehya (2010) eloquently argues that scarcity is embedded in two competing and often under-interrogated narratives, the "limits to growth" narrative and the neoclassical narrative. The former sees resources as finite and the expansion of human population and consumption, thus, as perilous. The second sees scarcity as relative, something that can be transcended through resource allocation. Both are grounded in long-held world views upon which these narratives and the policies that flow from them depend (Mehya, 2010: 18). This is an important point, as scarcity often emerges as a political strategy used to justify certain interventions (Mehya, 2010).

It has long been argued that the presumption of a universal scarcity is part of the human condition – a consequence of modernity and an ever-present condition of existence (Xenos, 1989). Recent contributions have sought to question universalist portrayals of scarcity and demonstrate that scarcity is the result of exclusion and unequal gender, social and power relations that legitimise skewed access to and control of finite and limited resources (Mehya, 2010). This positions scarcity as a relational concept that is often the result of market forces dictating issues concerning demand and supply (Mehya, 2010).

This leads to a second, related, point which is that because scarcity is relational, the 'who' of resource scarcity is important. The conceptualisation and experiential aspects of scarcity are varied and differ from one social actor to another, based on their social positions, spatial locations and temporal dimensions, as well as economic, political and cultural contexts (Sunil and Sasidevan, 2018). Nonetheless, scarcity tends to be universalised in academic and policy debates (Xenos, 1989) despite the fact that it is by definition a "…time bound and contextual phenomenon" (Mehya, 2010).

Thirdly, it is worth emphasising that scarcity is dynamically shaped by actors. The US Government, for example, can act in such a way as to restrict global access to a raw material it produces. It, thus, can make a material scarcer or more critical through its actions. Again, this serves to emphasise that there are no physical characteristics that make a material critical. Raw materials are classified as so because of the actions and perceptions of global actors.

2.1 Resource scarcity and growth

Food and water are essential to our survival and it stands to reason that concerns surrounding access to these resources are as old as mankind itself. Tilton (2006) cites the work of Maurice and Smithson (1984) who examined a sample of resource crises confronting various civilisations at different points in history and argues that the circumstances that brought about the first agrarian revolution and a shift away from hunter-gathering, for example, show how resource shortages and presumably concerns over resource availability can be traced far back in time. This is certainly true of metals and minerals too, with it being well documented that in the Bronze Age metals were transported huge distances to willing buyers, creating a situation of dependence on resources not available locally. These examples represent an early example of how material availability shaped the geographies of supply chains.

In more recent history, there has been considerable debate over the capacity of the planet to produce enough food to support its human population. While some hold, on technological grounds, that the Earth can adequately support several times its present population, others warn on ecological grounds that the Earth is already overpopulated and that human numbers should be reduced (Gilland, 1983). Two competing views on materials availability and depletion have endured over time (Tilton, 1996). The first is the fixed stock paradigm in which it is contended that the world cannot indefinitely continue to support current and anticipated levels of demand for exhaustible resources. The second is the opportunity cost paradigm, which argues that with the help of market incentives, appropriate policies and new technologies, the earth can amply provide for society's needs for the indefinite future. The former sees mineral resources as a fixed stock, gradually diminished through extraction, with the end-point to some extent measurable through comparing stock in the ground with the yearly drawing down of the stock. The latter assesses the availability of mineral commodities not in such absolute terms but in terms of the sacrifice that society must make for a mineral commodity, measurable with prices in a market economy (Humphreys, 2013). These competing views lead to division regarding long-run trends in the availability of mineral commodities and have, historically, led to differing opinions on the scarcity and long-term availability of particular raw materials (Tilton and Lagos, 2007).

Literature that explores the planet's ability to sustain an ever-increasing human population first emerged in the late eighteenth century. It was during this period that food was identified as a critical material of sorts, put at risk by mankind's proclivity for reproduction. In his 1776 work, 'The Wealth of Nations', Adam Smith (1985) asserted that every species of animal naturally multiplies in proportion to the means of their subsistence, and no species can ever multiply beyond it. Smith, therefore, foresaw a point at which access to food would serve as a natural check on population size. This rather fatalistic view was further explored by Thomas Malthus in his 1798 work, 'An Essay on the Principle of Population', written against the backdrop of the Corn Laws which imposed import duties on foreign grain to protect UK producers. Malthus (2008) supposed that it would be an error to assume that population and food production increase in the same rate, noting that population, when unchecked, increases in a geometrical ratio whereas subsistence increases in an arithmetical ratio. While history has shown Malthus' logic to have been somewhat misguided, his essay represents the first reasoned exploration of the limitations that finite resources could have on growth and development.

Industrialisation widened the focus of the debate. Discussions regarding access to other resources became more common, although the debate over agricultural capacity and food production continued. Writing in the nineteenth century, John Stuart Mill to some extent shared Malthus' concerns over food supply and population growth. However, unlike Malthus, Mill factored future developments in agricultural knowledge into his argument, as well as the likelihood that social institutions and increases in economic welfare may slow down the rate of population increase (Tahvonen, 2000). While identifying the limits to several natural resources, and noting that population growth increased demand for food and other materials, Mill emphasised that while the limited quantity of natural resources could, in principle, constrain increases in production, this limit had not yet been reached and would not be reached in any country over any meaningful time frame (Tahvonen, 2000).

Stanley Jevons saw the need for a greater sense of urgency. Prompted in a similar way to Malthus by changes to trade policies, in particular, certain stipulations of the 1860 Cobden–Chevalier Treaty which secured a free export of coal between Britain and France, Jevons explored the potential ramifications of Britain’s reliance on coal. In a departure from the Malthusian view of the relationship between population and production, Jevons (1865) suggested that even if each person continued to use an invariable quantity of coal per annum, the total produce would increase in the same ratio as the number of people. This difference in mathematical reasoning nonetheless provided Jevons with similar conclusions to Malthus, that is, that the continued exploitation of non-finite resources could not indefinitely support growth.

Widespread public concern over resource availability surfaced in the USA towards the end of the nineteenth century as industrialisation, coupled with the closing of the American frontier and the rapid exploitation of vast forest lands, prompted a political and social reaction (Tilton, 2006). Works such as those by Gifford Pinchot (1967) and others associated with the Conservation Movement were amongst the first to advocate the conservation of national resources through planning and sustainable renewal. It was, however, WWI that prompted widespread US attention of resource scarcity issues and gave the debate a military and economic perspective. During the conflict, many warring nations began to experience severe shortages of materials required to sustain their war efforts such as during the Shell Crisis of 1915, an allied shortage of shells on the front lines caused, in part, by Germany having secured control of the bulk of global tungsten production and leaving the allied forces with little access to this important material for the production of weapons and munitions (Chakhmouradian et al., 2015). Such shortages prompted the establishment of military stockpiling bodies in the USA in 1922 and USSR in 1931 (Chakhmouradian et al., 2015).

While there were several significant contributions to raw material dependence literature published between WWI and WWII (for a comprehensive list see Hall, 1940), the most important was undoubtedly Harold Hotelling’s ground-breaking paper, ‘The Economics of Exhaustible Resources’, which provided an assessment of the economic implications of non-renewable resource depletion. Hotelling’s formal analysis generated some basic implications for how the finite availability of a non-renewable resource affects the resource price and extraction paths (Krautkraemer, 1998). He highlighted, for the first time, the problems associated with low prices for exhaustible assets which he saw as fostering the selfish exploitation of resources and wastefulness in production and consumption (Hotelling, 1931). He also criticised the Conservation Movement and posited the notion that its focus on absolute prohibitions, as opposed to increased taxation or regulation so as to improve efficiency, could play into the hands of parties interested in maintaining high prices for personal gain (Hotelling, 1931).

By the start of WWII, numerous bills had been set before the US Congress aiming to remedy the resource scarcity situation, most of which advocated stockpiling (Hall, 1940). The end of the war prompted an increased focus on the assessment of available resources in the USA. The central question was whether the USA had the materials required to sustain its military dominance, as well as maintain high levels of economic growth and development. As new horizons of world expansion opened up after the war, concern with wise management of domestic resources gave way to an interest in assessing the availability of global raw materials (Dean, 1971; Walker, 1979). During this period, industrial figures, particularly those in the extractive sectors, began to publicly outline their views on the future of extractive enterprises (Hubbert, 1949) and there was significantly increased interest from government.

In 1951, President Truman established The President's Materials Policy Commission (PMPC), known as the Paley Commission after its chairman William S. Paley. The PMPC published the five-volume report, 'Resources for Freedom', in 1952. This report had as its principal objective an examination of the adequacy of materials, chiefly industrial materials, to meet the needs of the free world in the years ahead (Ackerman, 1953). Focussing upon assumed requirements for the 1951 to 1975 period, the report suggested that the USA's materials and energy problems would derive from a far greater capacity for consumption expansion than expansion in resource-based production. The report recommended an increased focus on exploration and discovery, recycling and renewable resources, finding uses for presently unemployed resources, synthesising new materials, and obtaining as many materials from abroad as possible. To improve the utilisation of foreign sources of materials, it was recommended that actions be taken to stimulate private investment for the development of low-cost production abroad, assist countries with surplus resources to improve their productive capacity, eliminate trade restrictions on materials, and promote greater stability for international materials markets (Engelbert, 1953).

On William S. Paley's recommendation, a permanent research body, Resources for the Future (RFF), was established in 1952 to carry out the work of relevant assessment and policy formation (Walker, 1979). RFF became the first US think tank devoted exclusively to natural resource and environmental issues. However, the views of the PMPC and RFF did not go unchallenged and one of the ironies of the history of ideas about natural resources is that in contrast to the fear of resource scarcity of the late 1940s which prompted the formation of the Paley Commission, the prodigal son, RFF, prompted the production of the modern, neoclassical gospel of anti-Malthusian thought (Walker, 1979, p.331). In 1963, Howard J. Barnett and Chandler Morse published 'Scarcity and growth' which interpreted data assembled by their colleagues Neal Potter and T. Francis Christy, Jr., and challenged the concerns over future sustainability that had led to the RFF's creation. Barnett and Morse made a compelling case that scarcity of the resources to which they devoted most of their attention did not yet, probably would not soon, and conceivably might not ever, halt economic growth (Simpson et al., 2004).

New approaches to analysis challenged the findings of 'Scarcity and Growth'. In 1972, scientists from the Massachusetts Institute of Technology published the 'Limits to Growth' report for the Club of Rome (Meadows et al., 1972). This study was based on a computer modelling approach and attempted to predict the future development of five global variables: population, food, industrialisation, non-renewable resources, and pollution. The report predicted that limits to growth were fast approaching and that global society ignored them at its collective peril (Simpson et al., 2004).

The 1973 Oil Crisis, in which members of Organisation of Arab Petroleum Exporting Countries announced an oil embargo in response to US support of Israel in the Yom Kippur War, provided empirical backing to those who espoused the importance of understanding the risks to growth. More than any academic contribution could, the crisis emphasised the significance of securing supply of raw materials to the global community, reflected in a glut of publications on energy and raw material sustainability from leading academics (Dasgupta and Heal, 1974; Stiglitz, 1974) and prompting further calls from government institutions for new analyses on raw material supply risk.

In a 1974 U.S. National Security Study Memorandum, the then President (Nixon) directed further examination of the potential threat posed by foreign manipulation of the supply or price of critical non-fuel commodities. Focussing on nineteen commodities, the subsequent report was the first major product by product examination of raw materials (Ad Hoc Inter-Agency Group on Critical Imported Materials, 1974). Similarly, a 1975 European Commission communication espoused the importance of Europe maintaining access to supply from developing countries and the resultant publication, titled 'Community's Supply of Raw Materials', was the first product by product examination of critical materials within a European context (CEC, 1975). The communication identified several materials as being of concern, based on a qualitative evaluation of supply and demand trends, substitutability, producer concentration, and political risk (Buijs et al., 2012).

Those who questioned the contemporary relevance of analyses on resource scarcity were not silenced but certainly became less vocal in the face of increasing levels of research and statistical rigour. In 1976, RFF held a conference to again investigate the topic of scarcity and growth. In many respects 'Scarcity and Growth Reconsidered' (Smith, 1979), the volume of collected papers and commentaries from that conference, echoed the optimism of its predecessor although some contributors did question whether Barnett and Morse's perspective was justified while others raised concerns regarding the limitations of the approach (Simpson et al., 2004). Importantly, several of its chapters focused on determining what it was that available data could tell the world about scarcity and growth, rather than on making pronouncements regarding long-term prospects from such data (Simpson et al., 2004).

2.2 Critical materials

The onset of multi-commodity examinations and data-driven approaches in the 1970s set the scene for contemporary critical materials studies. To reflect the increasing role of certain materials in mainstream manufacturing and new technological applications, the definition of critical materials was expanded beyond the military and defence sector in the 1980s (Chakhmouradian et al., 2015). Today, while the term critical materials has no universal definition, it is generally used to refer to metals and minerals which are of high economic importance to a particular industry, sector or spatial area and are at risk of supply shortage (Bedder, 2015). The Critical Raw Materials Alliance (CRM Alliance), an advocacy group created by industry in Europe to promote the importance of critical materials for the European economy defines critical raw materials as:

> "…those raw materials which are economically and strategically important for the…economy but have a high-risk associated with their supply. Used in environmental technologies, consumer electronics, health, steel-making, defence, space exploration, and aviation, these materials are not only 'critical' for key industry sectors and future applications, but also for the sustainable functioning of the… economy" (CRM Alliance, 2017).

In 1983, the US Bureau of Mines prepared a comprehensive analysis of strategic and critical minerals, describing such materials as those needed to supply the military, industrial, and civilian needs of the USA during a national defence emergency and whose supplies are dependent on imports (US Congressional Budget Office, 1983). The report identified 64 minerals and metals for which the USA was a net importer. It was not, however, until the 2000s that detailed reports of this nature became prevalent.

Articles and studies on critical materials became commonplace after the start of the new millennium. As an analysis of available literature of materials availability conducted by Speirs et al., (2013) shows, more papers have been published on critical materials since 2001 than were published on this subject in the preceding half-century. What's more, the publication of articles on critical materials has increased at a much faster rate than those on related materials availability subjects such as resource assessment, photovoltaic materials and recycling. This is a result of globalisation expediting the processes that led to a broadening of the critical materials definition in the 1980s. In particular, the recent commercialisation of new technologies (mobile telephones, tablets and alike) dependent on a range of minor metals has made certain materials increasingly important to a wide range of industries. Further, greater demand for raw materials resulting from the rapid industrialisation of China and other countries has highlighted the possibility of material shortages to a global audience and popularised terms such as critical and critical materials within business and political vernacular (Chakhmouradian et al., 2015). These factors, together with an increased global awareness of the high concentration of global production of certain materials in a small number of countries have led to increased interest in critical materials from government, industry and academics.

Resource security has been considered a priority by various regional, national and international bodies, evidenced by the development of numerous criticality studies and raw materials strategies in recent years (Table 1). Governmental raw material strategies are defined significantly by their country/region's position in the material supply chain: while some studies, such as that of Finland, are written from the perspective of a producer and exporter, others, such as that of Germany, are based on the viewpoint of a net importer, and significant consumer of non-renewable resources (Bedder, 2015). Criticality studies of this kind either scrutinise the economy (global, regional, national or sub-national) or a specific sector or technology from a criticality perspective (Table 1). There have also been industry-led studies into critical materials (see for example Cullbrand and Magnusson, 2012; Duclos et al., 2010) which focus on the criticality of materials that form part of the supply chain, and numerous material-focussed criticality studies have also been conducted including contributions on cobalt (Mudd et al., 2013), copper (Nassar e al., 2012), rare earth elements (Nassar et al., 2015), and groups of materials (Harper et al., 2014; Harper et al., 2015; Nuss et al., 2014; Panousi et al., 2015).

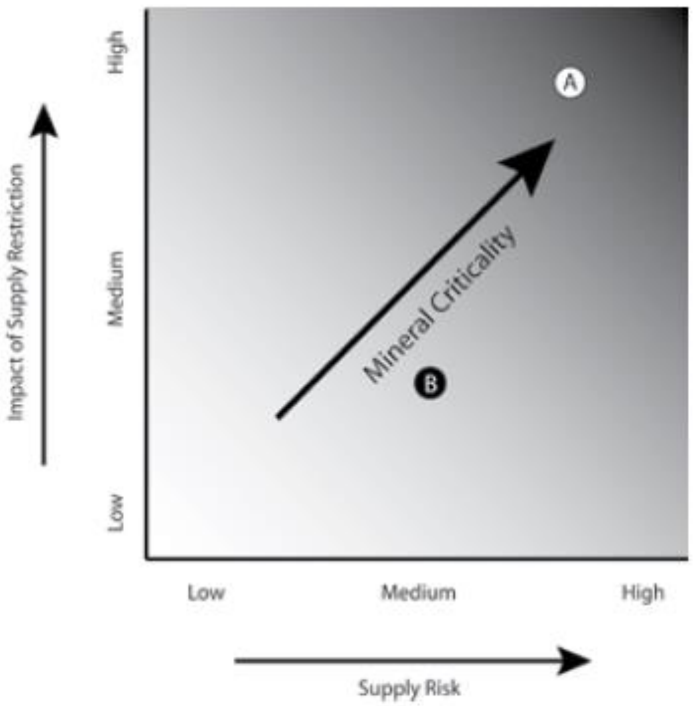
Table 1: Critical materials studies and raw material strategies published since 2000			
Area	Author	Study name (abridged)	Focus
Australia	Skirrow et al., 2013	Critical commodities for a high-tech world: Australia's potential to supply global demand.	Economy
EU	Cullbrand and Magnusson, 2012	The use of potentially critical materials in passenger cars	Sector
EU	EC, 2010	Critical raw materials for the EU	Economy
EU	EC, 2014	Report on critical raw materials for the EU	Economy
EU	EC, 2017	Study on the review of the list of Critical Raw Materials	Economy
EU	Moss et al., 2013	Critical metals in strategic energy technologies	Technology
Finland	Academy of Finland, 2014	Mineral resources and material substitution research programme	Economy
Finland[1]	Geological Survey of Finland, 2010	Finland's mineral strategy	Economy
Germany	Angerer et al., 2009	Raw materials for emerging technologies	Technology
Germany[1]	Federal Ministry of Economics and Technology, 2010	The German Government's raw materials strategy	Economy
Germany	IZT and Adelphi, 2010	Kritische Rohstoffe fur Deutschland	Economy
Germany	Pfleger et al., 2011	Rohstoffsituation Bayern: Keine Zukunft ohne Rohstoffe	Economy
Global	Bucher et al., 2009	Critical metals for future sustainable technologies and their recycling potential	Economy
Global	Graedel et al. 2015	Criticality of metals and metalloids	Economy
Global	Harper et al., 2014	Criticality of the geological zinc, tin, and lead family	Material
Global	Harper et al., 2015	The criticality of four nuclear energy metals	Material
Global	Mudd et al., 2013	Quantifying the recoverable resources of by-product metals: The case of cobalt	Material
Global	Nassar et al., 2012	Criticality of the geological copper family	Material
Global	Nassar et al., 2015	Criticality of the rare earth elements	Material
Global	Nuss et al., 2014	Criticality of iron and its principal alloying elements	Material
Global	Panousi et al., 2015	Criticality of seven speciality metals	Material
Japan[1]	METI, 2009	Announcement of "Strategy for ensuring stable supplies of rare metals"	Economy
Netherlands	Dutch Ministry of Foreign Affairs, 2011	Policy document on raw materials	Economy
Netherlands	PBL, 2011	Scarcity in a sea of plenty? Global resource scarcities and policies in the European Union and the Netherlands	Economy
Netherlands	Statistics Netherlands, 2010	Critical materials in the Dutch economy – preliminary results	Economy
OECD	Coulomb et al., 2015	Critical minerals today and in 2030	Economy
South Korea[1]	Bae, J-C, 2010	Strategies and perspectives for securing rare metals in Korea	Economy
Sweden[1]	Regeringskansliet, 2013	Sweden's minerals strategy	Economy
UK	BGS, 2011	Risk list 2011	Economy
UK	BGS, 2012	Risk list 2012	Economy
UK	BGS, 2015	Risk list 2015	Economy

UK	House of Commons Science and Technology Committee, 2011	Strategically important metals	Economy
UK	Oakdene Hollins, 2011	Study into the feasibility of protecting and removing critical raw materials through infrastructure development in the south east of England	Economy
USA	NRC, 2008	Minerals, critical minerals, on the U.S. economy	Economy
USA	Resnick Institute, 2011	Critical materials for sustainable energy applications	Sector/ Technology
USA	US DOD, 2013	Strategic and critical materials, 2013 report on stockpile requirements	Economy
USA	US DOD, 2015	Strategic and critical materials, 2015 report on stockpile requirements	Economy
USA	US DOE, 2010	Critical materials strategy	Sector/ Technology
USA	Schulz et al. 2017	Critical Mineral Resources of the US	Economy
Note: 1 = Raw materials strategy			

Several of the contributions outlined above have taken the form of multi-commodity assessments which seek to apply a wide range of measures to metals and minerals, allowing raw material availability to be quantitatively examined and compared. These studies all seek to develop and apply a methodology and identify critical materials from a candidate list (Bedder, 2015). In response to the recent glut in studies of this kind, there have been several recent contributions that have sought to classify the various methodologies utilised (Erdmann and Graedel, 2011; Glöser et al., 2015). Erdmann and Graedel (2011) note that over the past decade, the literature on critical materials has evolved, moving away from purely quantitative supply and demand analyses focused on long-term geological depletion, towards studies that also include more complex qualitative concepts and noted that most studies apply one of three methods for the assessment of criticality: criticality matrices, criticality indices, or quantitative future supply and demand analysis. Many studies have in common the evaluation of vulnerability of the system to a real supply disruption and of supply risk, particularly those that utilise a criticality matrix approach (see for example, Buchert et al., 2009; DOE, 2011; Duclos et al., 2010; EC, 2010; EC, 2014; EC, 2017; NRC 2008). The most commonly used conceptualisation of this evaluation methodology is that shown in Figure 6 where importance, or impact of supply restriction, is shown on the y-axis and supply risk is shown on the x-axis.

Figure 6: Criticality matrix

The criticality matrix as established in the NRC (2008) report allows evaluation of the criticality of a given mineral. A mineral is placed on this figure after assessing the impact of the mineral's supply restriction (importance in use on the y-axis) and the likelihood of a supply restriction for that mineral (x-axis). The degree of criticality increases from the lower left to the upper-right corner of the figure: in other words, mineral A is more critical than mineral B.



Source: NRC (2008)

Impact of supply restriction, or vulnerability, is either viewed negatively (as a threat) or positively (demonstrating importance) in criticality studies. For example, in the NRC study (2008), vulnerability was viewed positively through the interrogation of three indicators: the estimated value of US consumption of the mineral, the percentage of US consumption in existing uses for which substitution is difficult or impossible, and the report committee's professional judgment about the importance of growth in emerging uses that could overwhelm existing raw material production capacity in the short term. In the EC studies (EC 2010; EC 2014; EC 2017), vulnerability was measured positively as 'economic importance' of a given raw material to the economy.

Supply risk is a determinant of criticality in nearly all studies although the approaches to assessment differ. In the NRC (2008) study, the placement of a material on the horizontal axis (Figure 6) was based on the judgment of the report's committee, rather than the result of a quantitative analytical methodology. The committee assembled five indicators that related to current or future supply: US import dependence, the worldwide ratio of reserves to current production, the ratio of worldwide reserve base to current production, the relative importance of world by-product production in world primary production, and the relative importance of US secondary production from old scrap in overall US consumption. An adjusted version of this approach was utilised in the GE study (Duclos et al., 2010) and the US DOE (2011) study. In the EC studies (EC, 2010; EC, 2014; EC, 2017) evaluation of supply risk involved the formation of a composite indictor comprised of three factors: the concentration of primary supply from countries with poor governance, end-of-life recycling rates, and substitutability. To assess the concentration of supply from poorly governed states, country-level production statistics were taken from various sources and poor governance data was sourced from the World Bank's World Governance Indicator (WGI). Factors of concentration were considered through a modified Herfindahl–Hirschman Index, a measure of market concentration. Recycling rates data were taken from various sources to measure the proportion of material produced from end-of-life scrap and other residues. Measures of the difficulty to substitute a given material were estimated through expert judgement, and an aggregate score was calculated for each material which took into account substitutability for each of its uses. In the Öko-Institut study, (Buchert et al., 2009), several sub-criteria were used to prioritise materials in terms of supply risk: regional concentration of mining, physical scarcity, temporary scarcity, and structural or technical scarcity.

To summarise, either through expert judgement or a quantitative process, supply risk has been defined, in a critical materials context, through a range of indicators including import dependence, supply from countries with poor governance, reserve-to-production ratios, by-production analysis, recycling rates, substitutability, and physical scarcity. Given their subjective nature and, in particular, the temporal complexities that emerge when evaluating criticality, methodologies can always be subject to criticism. In any study of this kind, both methodological design and the selection of data sources have a profound impact on the classification of materials as critical, and any methodology that requires the selection of composite indictors is less than precise (Graedel et al., 2011). It is for this reason that there have been calls for further research into the selection of indicators, and their aggregation (Achzet and Helbig, 2013; Bedder, 2015; Glöser et al., 2015).

2.3 Critical material sector characteristics

As shown in chapter 2.2, most studies hold economic importance and supply risk as the key determinants of criticality. As such, critical materials cannot be said to have any unifying characteristics, other than those which derive from the methodologies used to select them. Nonetheless, it is useful, in order to provide context, to briefly outline some of the features of critical materials markets. This will enable the reader to better understand which countries and industries are being discussed where measures of supply risk and economic importance have been applied. As undertaking this process for all raw materials cited as critical would be unrealistic, several frequently cited examples have been selected and examined below.

2.3.1 Antimony

Antimony has featured in numerous risk lists and criticality studies (see for example BGS, 2010; BGS, 2011; BGS, 2015; Coulomb et al., 2015; EC, 2010; EC, 2014; EC, 2017). Principal identified world resources are in Australia, Bolivia, China, Mexico, Russia, South Africa, and Tajikistan (USGS, 2016). China is by far the world's largest resource holder and mine producer, accounting for 77% of global mine production in 2015 (USGS, 2016). The high concentration of mine production and processing of antimony in China plays a significant part in its classification as a critical material. What's more, Chinese control of the sector has become ever stronger, with China sourcing increasing quantities of antimony concentrate from non-domestic sources (Roskill, 2018). Antimony's use in a wide range of important industrial applications is the other reason for its critical label. Flame retardants were estimated to account for about one-half of global primary antimony consumption, followed by lead-acid batteries and plastics (USGS, 2016).

2.3.2 Chromium

World resources of chromite are estimated to be larger than 12Bnt of ore and about 95% of these resources are located in South Africa and Kazakhstan (EC, 2015). South Africa produced 56% of all mined chromite in 2015(USGS, 2016b), which results in the material being considered at supply risk in several critical materials studies (see for example Coulomb et al., 2015; EC, 2010; EC, 2014). Chromium is consumed in the form of ferrochromium to produce stainless steel. China is the leading chromium-consuming and ferrochromium-producing country and the leading stainless steel producer. Thus, a high proportion of production of the raw material (in South Africa) and the processed material (in China) is located in one country. Some 80% of ferrochrome is consumed in the production of stainless steel, where it imparts corrosion and oxidation resistance, and enhances hardenability, creep and impact resistance (Roskill, 2017a).

2.3.3 Niobium

Almost all world niobium reserves are located in Brazil although around 5% of global reserves are in Canada (EC, 2015). Approximately 90% of all niobium used is consumed as ferroniobium in steelmaking, while the rest goes into a wide range of smaller-volume but higher-value applications, such as high-performance alloys (which include superalloys), carbides, superconductors, electronic components and functional ceramics (Roskill, 2017b). With the steel sector being essential to the global economy, and with most niobium consumed in steel, it is clear why the material appears in numerous criticality studies (see for example BGS, 2010; BGS, 2011; BGS, 2015; Coulomb et al., 2015; EC, 2010; EC, 2014). Further, as almost all ferroniobium supply is from three industrialised producers in Brazil and Canada (Roskill, 2017b), this explains the concerns over the material's supply risk potential.

2.3.4 Rare Earth Elements

The term 'rare earth elements' (REEs) is a collective name for the 15 elements in the lanthanide group: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium. REEs are relatively abundant in the Earth's crust but discovered minable concentrations are less common than for most other ores (USGS, 2016l). China dominates both mine production and reserves of REEs and accounted for 85% of global supply in 2015 (USGS, 2016l). Rare earth elements are used for a wide variety of applications, although four markets (magnets, metallurgy, catalysts and polishing powder) account for nearly three-quarters of total rare earth use (EC, 2015).

2.3.5 Tungsten

World tungsten resources are geographically widespread and Canada, China, Kazakhstan, Russia, and the USA all have significant tungsten resources. World tungsten supply is dominated by production in China and exports from China; China is also the world's leading tungsten consumer (USGS, 2016k). China accounted for 82% of global tungsten mine supply in 2015 (USGS, 2016k). By far the largest market application for tungsten is in the production of cemented carbides, wear-resistant materials consisting of metal carbides held in a bonding matrix used across a range of sectors that are mainly related to heavy industry (Roskill, 2017c).

2.4 Selecting a case study critical material

In this sub-chapter, one critical material is selected for closer examination. As shown in chapter 2.2, critical materials studies typically either scrutinise the economy (global, regional, national or sub-national) or a specific sector or technology from a criticality perspective (Table 1). While certain materials frequently appear in more than one study, no one material can be said to be the *most* critical. This is because methodologies differ, certain materials are more/less important to different economies/sectors, and because ease of access to materials differs between actors.

Since the EC (2017), Schulz et al. (2017), and OECD (Coulomb et al., 2015) studies are recent and because they are both concerned with supply risk and economic importance of raw materials from the perspective of large geographic areas, the short-list of most critical materials presented in these reports is a sensible starting point for identifying a case study material for the purposes of this research. These are shown below.

Table 2: EC derived candidate materials for case study

The 27 raw materials identified as critical in the EC (2017) report from a list of 78 candidate materials

Antimony	Barytes	Beryllium	Bismuth	Borates
Cobalt	Coking coal	Fluorspar	Gallium	Germanium
Hafnium	Helium	Indium	Magnesium	Natural Graphite
Natural rubber	Niobium	Phosphate rock	Phosphorus	PGMs
REEs (Heavy)	REEs (Light)	Scandium	Silicon metal	Tantalum
Tungsten	Vanadium			

Source: EC (2017)

Table 3: OECD derived candidate materials for case study

The 21 minerals identified as critical in the 2015 OECD report from a list of 51 candidate materials

Antimony	Barytes	Beryllium	Borates	Chromium
Cobalt	Fluorspar	Gallium	Germanium	Indium
Magnesite	Magnesium	Natural Graphite	Niobium	PGMs
Phosphate Rock	REEs (Heavy)	REEs (Light)	Silicon Metal	Tungsten
Vanadium				

Source: Coulomb et al., (2015)

Table 4: USA derived candidate materials for case study

The 23 raw materials identified as critical in the Schulz et al. (2017) report

Antimony	Barytes	Beryllium	Cobalt	Fluorine
Gallium	Germanium	Hafnium	Indium	Lithium
Manganese	Natural graphite	Niobium	PGMs	REEs
Rhenium	Selenium	Tantalum	Tellurium	Tin
Titanium	Vanadium	Zirconium		

Source: Schulz et al. (2017)

Materials not listed as critical in all studies are discounted. These are bismuth, chromium, coking coal, fluorine, hafnium, helium, lithium, manganese, magnesite, natural rubber, phosphorus, rhenium, scandium, tantalum, tellurium, tin, titanium, and zirconium. It is also necessary to discount groups of metals and minerals which will be too cumbersome for detailed analysis. Thus, barytes, borates, phosphate rock, the seventeen chemical elements known as rare earth elements (REEs) and the six platinum group metals (PGMs) are not suitable as a case study and are discounted.

As this thesis seeks to better understand the sprawling supply chains that characterise the modern global economy, it is necessary to also discount materials which are mostly produced and consumed in the same state. Such materials will not make for suitable case studies as a high concentration of production, consumption and transportation takes place within one jurisdiction. For this reason, beryllium (produced and consumed mainly in the USA), and antimony, fluorspar, germanium, magnesium, natural graphite, silicon metal, tungsten and vanadium (all produced and consumed mainly in China) are discounted (USGS, 2012b; USGS, 2016; USGS, 2016a; USGS, 2016d; USGS, 2016f; USGS, 2016h; USGS, 2016j; USGS, 2016k). Materials that are only produced, consumed and trade in small volumes will also not make a suitable case study as there are only a small number of producers/consumers engaged in such sectors. Gallium production was estimated at 435t in 2015, and indium production was put at 755t in 2015 and, as such, these materials are also discounted (USGS, 2016e; USGS, 2016g). As a result, cobalt and niobium are shortlisted for case study selection (Table 5).

Table 5: Shortlist of candidate materials for case study

For the reasons set out in the preceding text, certain metals and minerals have been discounted, represented via a strike-through.

~~Antimony~~	~~Barytes~~	~~Beryllium~~	~~Bismuth~~	~~Borates~~
~~Chromium~~	Cobalt	~~Coking coal~~	~~Fluorine~~	~~Fluorspar~~
~~Gallium~~	~~Germanium~~	~~Hafnium~~	~~Helium~~	~~Indium~~
~~Lithium~~	~~Manganese~~	~~Magnesite~~	~~Magnesium~~	~~Natural Graphite~~
~~Natural rubber~~	Niobium	~~Phosphate rock~~	~~Phosphorus~~	~~PGMs~~
~~REEs (Heavy)~~	~~REEs (Light)~~	~~Rhenium~~	~~Scandium~~	~~Selenium~~
~~Silicon metal~~	~~Tantalum~~	~~Tellurium~~	~~Tin~~	~~Titanium~~
~~Tungsten~~	~~Vanadium~~	~~Zirconium~~		

Source: Coulomb et al., (2015); EC, (2017); Schulz et al. (2017)

The cobalt and niobium sectors are very different. Cobalt is consumed in refined metal and chemical forms with the batteries sector consuming the highest quantities (USGS, 2016c). China is the biggest producer and consumer of refined cobalt, with much of China's feedstock imported from the DRC, the world's leading source of mined cobalt (USGS, 2016c). Niobium is mostly consumed in the form of ferroniobium and used in certain steels. China was the world's leading consumer of ferroniobium in 2015 (USGS, 2016i). Brazil was the world's leading niobium mine producer and produces most of the world's ferroniobium (USGS, 2016i).

In the case of niobium, mineral production is converted, on a large scale, into ferroniobium in the country that it is mined (Brazil). Thus, a higher concentration of production, consumption and transportation takes place within one jurisdiction than is the case with cobalt. Owing to this research's focus on global supply chains, niobium is, therefore, discounted and cobalt is selected as the case study material.

While the methodology for selection set out above discounted some raw materials based on their absence from certain studies, their geographies, or the fact that they represent groups of numerous elements, a recent criticality study serves to confirm that cobalt is a suitable case study by virtue of the fact that it is regularly classified as critical. In a review of 32 criticality studies, Hayes and McCollough (2018) found that the three materials most commonly identified as critical are REE, PGM, and indium, while others identified as critical by more than half the studies include: tungsten, germanium, cobalt, niobium, tantalum, gallium, and antimony.

2.5 Cobalt: a critical metal?

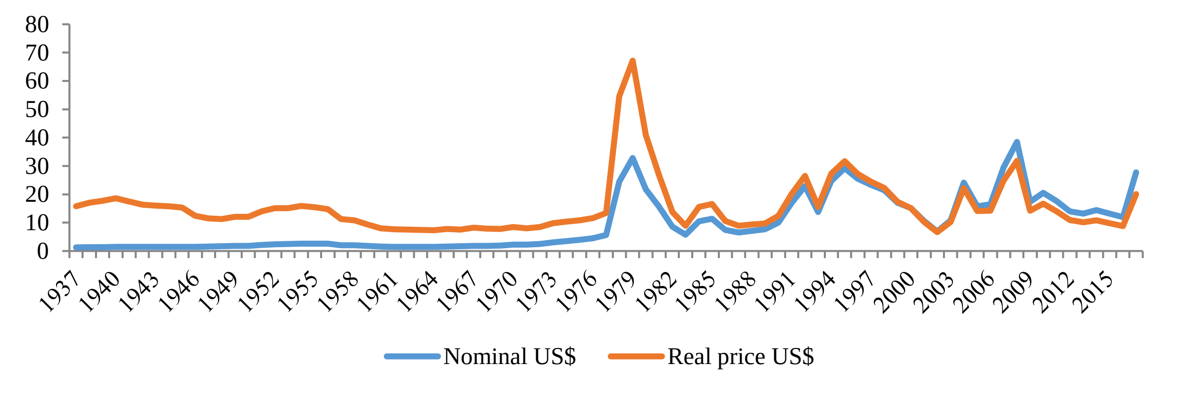
As noted above, while the term critical materials has no universal definition, it is generally used to refer to metals and minerals which are of high economic importance to a particular industry, sector or spatial area and are at risk of supply shortage (Bedder, 2015). Many criticality studies have in common the utilisation of a matrix approach (see for example, Buchert et al., 2009; DOE, 2011; Duclos et al., 2010; EC, 2010; EC, 2014; EC, 2017; NRC 2008), classifying materials as critical based on their economic importance to key global sectors, and the concentration of mine production in a small number of states.

As will be shown in Part II of this research, cobalt is mostly produced in the DRC and consumed in the production of battery materials, nickel alloys and other materials that are themselves consumed by a wide number of key industrial sectors. The high level of concentration of mine production in the DRC, together with enormous demand growth for cobalt and its consumption in key sectors such as aerospace, construction and automotive, is, therefore, the principal reason for cobalt's critical label.

Outside of the literature on critical materials, the cobalt market has been considered in light of materials availability in one other study which focusses on the outcomes of cobalt market developments in the

1970s (Alonso et al., 2011). This study discusses how in the 1970s, there was an incredible spike in the price of cobalt following a rebellion in Zaire (now the DRC) which at the time accounted for roughly 40% of global cobalt mine production. While production and supply were never greatly affected by the two-week rebellion, the uprising coincided with a global economic upturn that brought about increased demand for many raw materials, including cobalt. Demand from countries such as the USA (the world's major consumer which mined no cobalt domestically[1]), concern over supply shortages, and delays in transporting cobalt out to Western countries led to consumer panic, buying and speculation (Alonso et al., 2011). Between 1977 and 1979, the price of cobalt increased by 380%, considerably higher than the 40% swings that were typical of the period, and well above the 4% year-on-year changes that have become commonplace since 2010.

Figure 7: World: Average annual price for cobalt metal, 1937 to 2017 (US$/lb)



Source: Roskill (2018)

Note: Real prices adjusted to constant US dollars (2000) using United States GDP deflator data from the International Monetary Fund's World Economic Outlook Database

The price spikes associated with the events of the late 1970s, often dubbed the 'Cobalt Crisis', suggest that concerns surrounding supply risk can have a powerful impact on the cobalt price. What, though, was the impact of supply risk on supply chain structure and the geographies of the cobalt market?

Evidence suggests that the crisis had an impact on attitudes towards cobalt access in non-resource holding states. Holden (1981) noted that there was growing US concern over the Soviet Union's attempt to move in on mineral-rich areas of the globe and how after Angolan troops invaded Shaba Province in Zaire, the price of cobalt quadrupled just after the Soviet Union had made large purchases. An NMAB (1981) study highlighted how, following the invasion of Shaba Province, the US Department of State

[1] There was some cobalt produced from the Blackbird Mine in Idaho up until the late 1960s

sent experts to the country to examine the damage to cobalt mines and maintained communication with the Government to ensure the continuous supply of cobalt to US consumer. It noted that a direct option open to the US Government was to invoke the Defence Production Act to build up stockpiles and encourage domestic development of deposits (NMAB, 1981). In 1983, the US Bureau of Mines included cobalt in a comprehensive analysis of strategic and critical minerals for the military, industrial, and civilian needs of the USA during a national defence emergency and whose supplies were dependent on imports (US Congressional Budget Office, 1983). A further study provided a detailed analysis of US dependence on foreign sources of cobalt Blechman and Sloss (1985) and another (Jones, 1988) noted how of all the minerals upon which the United States was dependent for foreign sources of supply, chromium, cobalt, manganese, and platinum group metals were the most critical and sometimes referred to as ‘first tier’ strategic materials because of their widespread role and vulnerability to supply disruptions.

Evidence suggests that as well as attitudes, the structure of the cobalt chain changed after the Cobalt Crisis. During the 1980s, declining output by the two main African producing countries (Zaire and Zambia) was offset by increased production in other countries. This changed the dynamics of the cobalt market. The influence of African producers faded while, at the same time, a free market for cobalt developed. It is difficult to assert that these changes came about only because of fears over material availability. It is likely that they were driven by a host of factors.

The aforementioned study of the cobalt supply chain and the Cobalt Crisis, *Material Availability and the Supply Chain: Risks, Effects, and Responses*, argued that there are specific outcomes – technological, operational, and geographic – which can be expected within supply chains when limitations on materials emerge (Alonso et al., 2011). It was argued that supply chain stakeholders may redesign their products to use less cobalt or substitute materials (technological), the upstream supply chain may reconfigure to tap into new sources (geographic) and downstream firms may alter inventory practices or work to recover alternative materials streams (operational).

Regarding the geographic element, Alonso et al., (2011) found that short-term efforts concentrated on improving the lead times that had increased due to the political disturbance such as transporting some of the cobalt out of Zaire by air to major world markets. Further, longer-term efforts in Zaire were aimed at stabilising and expanding existing mining operations primarily through the assistance of loans obtained from the World Bank and the Libyan Arab Bank. It was also found that US mining companies considered their own resources, but that in the long term, the USA did not pursue any options to increase domestic production as the drop in cobalt prices in the 1980s made domestic mining uneconomic. Instead, the study suggested that the most effective response was the increase in recycling efforts, resulting in a doubling of cobalt recovery after 1978 (Alonso et al., 2011).

Based on the findings of Alonso et al., (2011), it would be expected that both changes to attitudes and specific technological, operational, and geographic outcomes would be expected from a period of perceived criticality. These themes will be re-explored in this dissertation's conclusion.

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This dissertation is concerned with how cobalt's criticality has brought about reconfigurations of the cobalt supply chain, influenced the tactics of key actors, and shaped the geographies of resource extraction, production, and consumption.

Focussing on the 2007 to 2017 period, the aim of this research is to determine how the cobalt supply chain is structured and organised, how its structure and organisation have evolved temporally and geographically, how firms and non-firm actors have responded to cobalt's criticality (supply risk and demand growth), and how these responses have resulted in spatial and structural outcomes. The research aims to identify the behaviours that have shaped various outcomes in the cobalt supply chain, as well as the outcomes themselves.

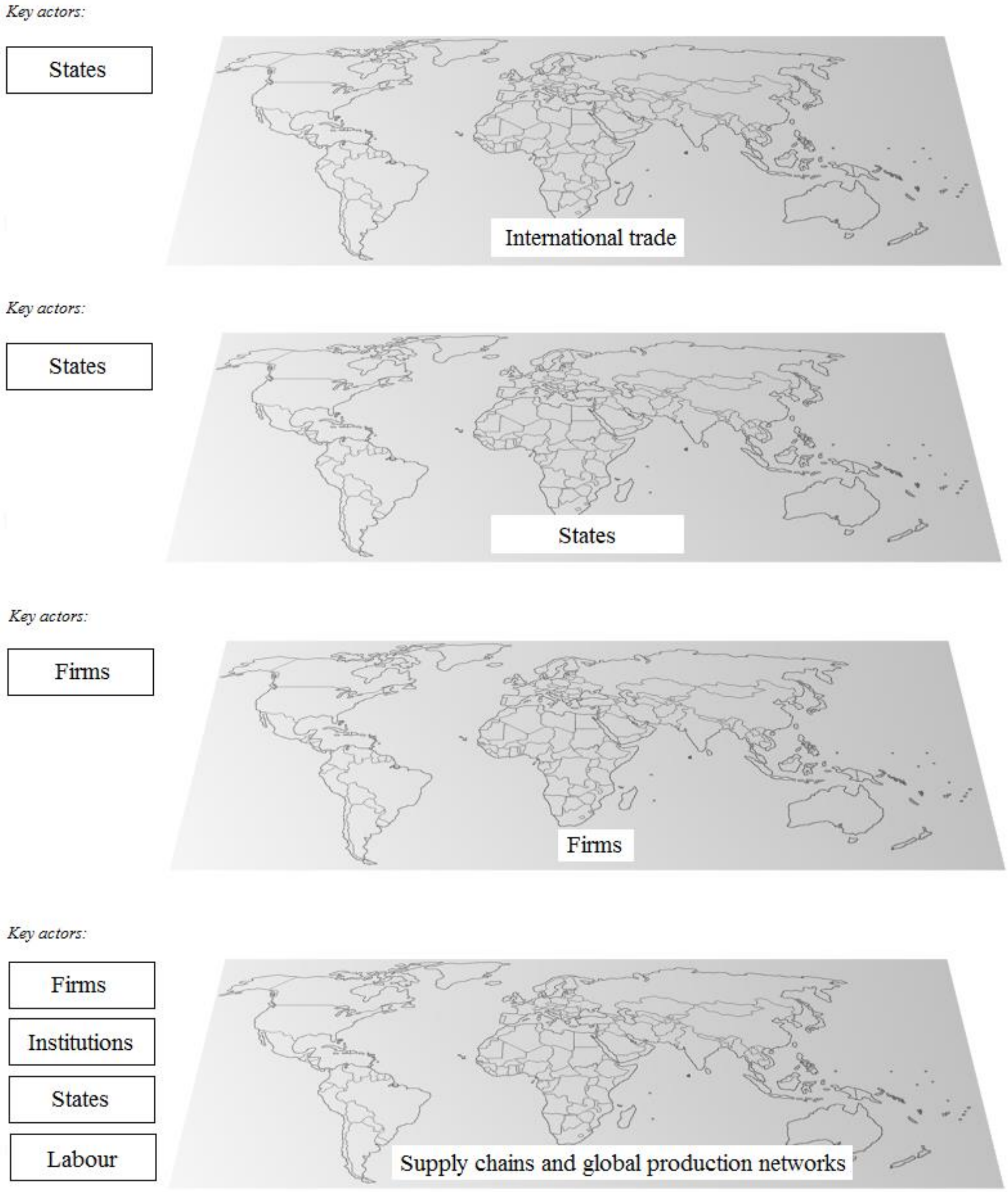
An important next step to achieve this is to consider what we know about raw material supply chains and the processes and actors within them. Thus, chapter 3 contains a review of four relevant bodies of literature: theories of international trade, theories of the state, theories of the firm, and global chains and production networks – and examines how and why global supply chains are formed and organised.

3. Theoretical debates on the nature and organisation of global supply chains

This chapter reviews four bodies of literature relevant to this research. These are as follows: literature on international trade; literature on states with natural resource endowments; literature on theories of the firm; and literature on global chains and networks. This review of the literature serves the purpose of establishing what we know about why and how structural and spatial outcomes have occurred in critical materials supply chains. In each case, the literature is reviewed. In cases where the literature is important for the subsequent empirical analysis in this dissertation, theories and concepts are then briefly considered in light of the cobalt sector. By exploring four key theoretical areas (Figure 8), the research benefits from a broad range of theoretical and conceptual ideas.

Figure 8: A four-tier framework for cobalt supply chain analysis and literature review

States are traditionally the key actor in the literature on international trade, although recent theories have industry and firms as the key units of analysis. Firms underpin international trade as, in reality, companies trade not companies. States are also the focus of theories related to state formation, organisation and development although state bargaining with firms is of central importance. In global production network (GPN) thinking, key actors are firms, extra-firm actors and intermediaries. Thus, GPN analysis, while focussing mainly on firms, also takes into account states and institutions.



Source: Author's construction

3.1 Theories of international trade

There is a rich history to the theorisation of international trade. In the introduction to his 2011 book, *Understanding Global Trade*, Elhanan Helpman (2011, p.9) identifies the need to highlight '…the interplay between theory and evidence', when charting the historical evolution of trade theory. Helpman (2011) argues that the evolution of scholarly literature on international trade has involved a chain of developing theories, empirical investigation that confirms or disproves parts of these theories, and updating theories based on new evidence, with all contributions cultivated by the contexts of their time, in order to make sense of international goods exchanges.

3.1.1 Classical trade theories

Early, or classical, trade theories were born out of a desire to better understand *why* and *how* countries trade. As is the case with the literature on resource scarcity, the first discussions of international trade can be traced to the writings of the British classical economists whose analyses showed that countries trade to exploit advantages rooted in their natural differences.

In part as a reaction to mercantilism, Adam Smith (1999) observed that certain countries have natural advantages for the production of particular commodities. Smith noted that it was illogical to produce products domestically which would necessitate additional resources beyond those required to procure such products through exchange with a foreign country. It was through the development of Smith's ideas on natural advantage that David Ricardo formulated his most celebrated theory in his 1817 work, *On the Principles of Political Economy, and Taxation*. Through his famous example of trade in wine and cloth between Portugal and England, Ricardo asserted that patterns of specialisation and trade were not determined by absolute advantage but comparative advantage (Ricardo, 2004).

Ricardo's neoclassical theory of static comparative advantage provided a foundation for further examination of inter-industry, inter-country trade. Nonetheless, Ricardo's view of foreign trade dominated economic discourse for a whole century and only in 1919 did a major challenge to his doctrine emerge (Helpman, 2011). Eli Heckscher and his student, Bertil Ohlin, incorporated not only labour, but also other key factors, capital and land, to their examinations of the determinants of patterns of specialisation and international trade (Ohlin, 1991). The Heckscher-Ohlin theory asserted that countries produce and export goods that require abundant factors of production and import goods for which they have limited resources for production. That is, trade and specialisation are dependent on a country's comparative advantage in certain factors of production. Thus, trade occurs because certain countries have inherent factors that make production cheaper.

A number of scholars built upon the Heckscher-Ohlin neo-classical approach with noteworthy contributions examining the impact of international trade upon relative factor prices (Stolper and Samuelson, 1941; Leamer, 1984) and the effects of factor endowments on output levels (Rybczynski, 1955). Perhaps the most well-known empirical examination based on Heckscher-Ohlin was that of Leontief (1977), who found a tendency for exports to be more labour intensive than imports in the United States. Given that the USA had a high capital-to-labour ratio, this finding went against the logic of neo-classical trade theory in which the US would import, as opposed to export, labour-intensive products.

3.1.2 New trade theories

While classical approaches adequately explained ‘dissimilar-dissimilar trade’, that is, trade in dissimilar goods between dissimilar countries, they failed to provide the theoretical basis for the increasing levels of ‘similar-similar trade’, that is, trade of similar products between similar countries, that was becoming more and more commonplace (Krugman, 2009). Against this backdrop, ‘New trade theory’ (NTT) emerged in the late 1970s and 1980s. Shifting focus towards the ‘industry’ as opposed to the ‘country’ NTT took into account increasing returns and imperfect competition (see Lancaster, 1980; Krugman, 2000). NTT effectively sought to explore why intra-industry trade between similar countries exists.

Since NTT gained prominence, theoretical research in international trade has increasingly emphasised firm-level decisions in understanding the causes and consequences of aggregate trade (Melitz and Redding, 2012). ‘New-new trade theory’, (NNTT) developed out of analysis of data that overwhelmingly substantiated the existence of large and persistent productivity differences amongst firms in the same narrowly defined industries (Melitz, 2003). This approach shared many of the features of NTT, but incorporated differences in firms' characteristics both within and across industries, and shifted the unit of trade analysis from the industry to the firm (Ciuriak et al., 2011). NNTT emphasized heterogeneity in productivity, size and other characteristics even within narrowly-defined industries (Melitz and Redding, 2012). NNTT posits that only highly productive firms are able to make sufficient profits to cover the large fixed costs required for export operations (Melitz, 2003; Helpman et al. 2004) Thus, according to NNTT firm heterogeneity is systematically related to trade participation, with exporters larger and more productive than non-exporters even prior to entering export markets (Melitz and Redding, 2012).

3.1.3 Network approaches to international trade

Network approaches to international trade analysis have become increasingly commonplace in recent years. After WWII, Ricardo's comparative advantage and the Heckscher-Ohlin theory had limited success in explaining trade patterns and the observed impact of trade liberalisation (Ciuriak et al., 2011). Empirical evidence that seemed to contradict and challenge key elements of classical trade theory prompted new approaches to trade analysis. Access to reliable trade statistics, which became increasingly available as the twentieth century progressed, also stimulated new, innovative data-driven methodologies.

One such innovative approach was the 'gravity model', introduced by Tinbergen (1962), who analysed the bilateral trade of goods between countries. The model proposed that the flow of trade between two countries was relative to their market sizes (measured by GDP) and the distance between them. While the model was widely studied and applied, it was found to produce results at odds with economic theory and notably failed to account for the impact on changes to the trade relations of two countries on those countries' trade relations with other trade partners (Shepard, 2012). This key limitation of the gravity model, namely its focus only upon bilateral trade relations, is representative of a core issue with many historical approaches to trade analysis – that many were derived with restrictive assumptions, partly for the sake of mathematical simplicity, and focussed on interactions between two hypothetical countries (Helpman, 2011). Whilst the gravity model addressed some of these inadequacies through its data-driven approach, its two-country focus resulted in some of the wider outcomes, and knock-on effects, of bilateral exchanges being overlooked.

A 'network approach' to international trade analysis, where the interactions between *all* countries engaged in trade are observed, was born out of a realisation of the limitations of models focussed on bilateral trade relations. A number of economists moved away from the two-country world of international trade theory and the bilateral focus of trade empirics, to a more global analysis, where the possible role of third countries, or more generally of the structure of the links among all countries is taken into account (Abbate et al., 2012, p.2). While international economists have conceived international trade as a network for decades, it is only recently that economic geographers, economists and social network scholars have started to go beyond graphical visualisation and explore the structural characteristics of the 'World Trade Network' or 'International Trade Network' and into its properties (De Benedictis and Tajoli, 2011). In keeping with network approaches in other disciplines (see for example, Albert and Barabasi, 2002; Caldarelli, 2007; Gluckler, 2007; and Barrat et al., 2008), analysis of the international trade network has typically taken the form of investigations in which international trade flows are examined using graph-theoretic structures where countries (vertices, or nodes) are linked by edges or links (representing the value/volume of a trade) to show import-export relationships between countries (Bhattacharya et al., 2007; Benedictis & Tajoli, 2011; Abbate et al., 2012).

Most studies of international trade from a network perspective have involved analysis of the evolution over time of the topological properties of the international trade network and have uncovered interesting insights into international trade flows, the architecture of the international trade network, and how these change over time. The majority of studies have focussed on international trade at an aggregate level with links between countries (vertices or nodes) representative of all commodities traded (Bhattacharya et al., 2007; Benedictis & Tajoli, 2011; Abbate et al., 2012). However, some studies have taken a commodity-specific approach (also referred to as a multi-network approach) to analysis of the international trade network (Reichardt and White, 2007; Paulette et al., 2009; Barigozzi et al., 2010; Fernandez et al., 2011). These employ data on specific commodity classes to identify stylised facts about the international trade network and have examined, in particular, whether trade architectures are heterogeneous across commodity-specific networks and the extent to which the topological properties of the international trade network are dependent on those of the commodity-specific networks that underpin it.

3.1.3.1 Network approaches to international trade and the cobalt sector

As network approaches do not constitute a theory, they have little explanatory power to explain why the cobalt supply chain is structured as it is. They do, however, represent an excellent way of evidencing how the cobalt chain is structured.

There has, to date, been no study of the cobalt ITN. Indeed, there have been very few studies of commodity-specific ITNs and hardly any that focus on only one metal or mineral. This presents an opportunity to uncover detailed, stylised facts about the architecture of the cobalt trade network for the purposes of this research.

3.2 Theories of the state

There are various theories of state formation, organisation and development. Of particular relevance to this research are theories that explain these factors with regard to states with natural resource endowments.

There is a good deal of literature that examines the role of states in extractive sectors. Given the heterogeneous geology of the planet, economic concentrations of mineral resources are spread unevenly across the globe. Certain states have an abundance of mineral wealth while others have little. Natural resource endowments pose policy choices for resource-rich governments (Wilson, 2015). Indeed, the absence of natural resource endowments also poses policy choices to governments, who must decide whether the issue needs to be addressed through state action.

Resource-holding states are able to secure economic rents from their natural resource endowments and must decide how best to do so. This requires a suitable regulatory environment to foster mine and processing infrastructure development as well as a degree of openness to international markets so that subsequent export to global partners is possible (Wilson, 2015). Typically, resource-holding states seek to create conditions to attract foreign investment and infrastructure development, but this is not always the case. Importantly such conditions can change over time.

Below, three key theories related to extractive sector states, and relevant to this research, are set out.

3.2.1 Resource nationalism

The term ‘resource nationalism’ has no set definition and can encompass nationalisation and expropriation of foreign companies, export restrictions, cartel pricing behaviour or high taxation (HM Government, 2014). Generally speaking, the term is used to reflect governmental policies or activities designed to restrict the international supply of a natural resource to the state’s advantage. Resource nationalism is generally construed either as a strategy to protect national interests or an opportunistic tactic to take advantage of capitalist market upswings (Kaup and Gellert, 2017).

Theories of resource nationalism centre around economic bargaining models. These theorise the phenomenon as the outcome of firm-state negotiations at different points of macroeconomic commodity cycles. Two key theories predominate. The first is the ‘market cycle theory’ and can be traced to Wilson (1987) who explored the theory through analysis of the oil sector. Others have applied the theory to the energy and mining sectors (Joffe et al., 2009; Lee et al., 2012). This theory suggests that market cycles are the key determinate of firm-state bargaining activities and subsequent resource nationalism in commodity markets. At the point in a commodity cycle when demand and prices are high, firm demand for state-owned assets is also high. At this point, states hold more power in the bargaining process and can demand more of firms in terms of taxation, royalties etc. Conversely, at the bottom of a commodity cycle, when prices and demand are low, firms have more bargaining power over states and can demand more of states. Firms could demand better terms, or more liberal policies, through either explicit or implied threats to withhold investment (Wilson, 2015).

The second is the 'obsolescing bargaining model' and is attributed to Vernon (1971) and Mikesell (1971). This theory also understands resource nationalism as a consequence of state-firm bargaining but instead identifies the maturity of a nation's resource industries as the key explanatory variable (Wilson, 2015). Put another way, it suggests that power dynamics between governments and multinational corporations in the extractives industry shift over time in the government's favour (Ostrowski, 2013). The theory argues that when resource projects, such as mines or wells, are first constructed, firms have more power in the bargaining process. This is because at such points, states require firms to inject capital and expertise in order to develop the project and associated infrastructure. As such, states are compelled to create conditions that incentivise investment. However, once assets are fully developed, the bargaining power moves in favour of states as firms have sunk their investment into projects that cannot be relocated. The initially generous bargains 'obsolesce', enabling states to impose increasingly onerous regulatory commitments (Wilson, 2015). As Moran (1992) notes, the key driver of resource nationalism according to this model is the industrial maturity of resource industries as states offer liberal conditions to incentivise investment at first, but firms ultimately become hostage to the demands of their hosts as industries mature.

Critics of these theories typically note their economic focus and their lack of focus on political factors (Domjan and Stone, 2010; Wilson, 2015). Other approaches have given a more central role to political dynamics such as political systems Mares (2010), political institutions (Wilson, 2015) and political goals (Domjan and Stone, 2010).

3.2.1.1 Resource nationalism and the cobalt sector

Theories of resource nationalism are highly applicable to the cobalt sector as a result of the high concentration of cobalt mine production in Central Africa. Both the governments of the Democratic Republic of the Congo and Zambia have been accused of nationalist thinking with regard to their cobalt and copper sectors (James, 2018). A widely cited example is the DRC government's seizure of the Kolwezi copper/cobalt project in 2009 citing suspected wide-scale misconduct. The project had been developed by First Quantum Minerals and the World Bank's International Finance Corporation (MacNamara and Thompson, 2010) but was seized by the state. More recently, in 2018, both the DRC and Zambian governments revised their mining codes to increase the royalties paid for copper and cobalt. Zeuner (2018) argues that the revision of the DRC mining code represents the developing shift in bargaining power and serves as evidence of the obsolescing bargain theory.

3.2.2 Rentier state theory

Another theory related to resource-rich states is rentier state theory. The notion of the rentier state is first attributed to Mahdavy (1970) and describes a state which derives a significant amount of its revenues from the rent of resources. The term is often associated with oil-generating states in the Arab world but is applicable in other settings to describe a state that is structurally dependent on the capture and distribution of natural resource revenues. Rentier states derive most of their revenues from the outside world and the functioning of their political system depends to a large degree on accruing external revenues that can be classified as rents (Schwarz, 2008). In rentier states, domestic political institutions are built around the extraction and distribution of economic rents and regime security is augmented by control of the distribution of resource rents, which allow regimes to foster support, and finance social welfare programmes as well as repressive apparatuses (Wilson, 2015, p.403).

Rentier state theory can be considered a political-economic theory that argues that resource-rich countries who are economically dependent on concessions paid for natural resource rights are more likely to be financially autonomous from their citizenry (Zeuner, 2018, p.3). This financial autonomy is reasoned to yield more authoritarian forms of governance as the state is not financially dependent on its citizenry through taxation, for example (Zeuner, 2018, p.3). Resource nationalism is connected to rentierism where state institutions are built around the extraction and capture of economic rents by the state and can be used by state elites to secure legitimacy through populist or authoritarian measures (Wilson, 2015).

3.2.3 Resource curse theory

The 'resource curse' theory "…is a body of political and economic literature which examines the link between resource abundance and poor economic growth" (Matti, 2010, p.402). It describes an apparent inverse relationship between these two phenomena and has been used to explain the failure of many states with abundant natural resources to benefit fully from their endowment. While at face value, an abundance of natural resources should work in a country's favour, the consensus on the experience and record of resource-rich economies has generally been discouraging, giving credence to the notion of a 'curse' (Matti, 2010). The resource curse can be defined as the effects of a country's natural resource endowment on its economic, social and political development. Murshed (2018: 1) frames the concept as "…the stylized fact that developing countries richly endowed with, or heavily dependent on, natural-resource-based economic activities on the whole consistently underperform compared to resource-"poor" developing countries". The apparent symptoms include a reduction in democratic accountability, bureaucratic effectiveness, and female labour force participation and a rise in economic volatility, corruption, and the likelihood of civil war (Ross, 2012).

The principal theory behind the resource curse is that the rapid growth in one sector of an economy results in a decline in others; typically, the traded sectors of economies. The theory is often applied to explain the economic effects of natural resource discoveries on their host state. The theory can also be applied to explain the economic effects of increased demand for, and prices of, certain natural resources on their host state. Following the development of a large natural resource asset, a nation's natural resource revenues may increase, but so too may the strength of that nation's currency. As such, over time, the nation's traded outputs become more expensive to purchase and thus uncompetitive globally, while imports become cheaper. Thus, the natural resource sector boom leads to higher revenue and spending but also an economic reallocation in which the country moves from a manufacturing-based economy towards a service-based economy.

Innis (1956) was one of the first to theorise the limitations of resource extraction based on his examination of development in Canada attributable to its position as an exporter of furs, fish, timber, grains and other raw materials to Europe. He argued that specialisation in extractive activities resulted in a dependent form of development, termed the staples trap, rather than a basis for wider economic diversification and development. But it was in the second half of the twentieth century that the notion of a resource curse gained prominence. From the 1970s onwards, a literature evolved with a focus on the macroeconomic problems faced by economies that had received a windfall from natural resource booms (Murshed, 2018). The Economist (1977) coined the term "Dutch disease", to describe the decline of Dutch manufacturing following the discovery of natural gas in the 1950s. The UK went through a similar decline in manufacturing after the discovery of North Sea oil in the 1970s. It has been argued that these discoveries resulted in inflationary pressures brought about by greater spending, real exchange rate appreciation, premature deindustrialisation and, as a result, issues such as unemployment (Rodrick, 2016; Murshed, 2018).

It wasn't until two decades later that the literature became focussed on developing countries. Murshed (2018) argues that the increased interest in the resource curse towards the end of the twentieth century is attributable to the extraordinary economic success achieved by certain resource poor-East Asian countries, such as South Korea, in contrast to the relative decline in resource-rich Latin America and Africa. Investigations have taken numerous forms. Bridge (2008) neatly synthesises the literature into four groups: First, are micro-economic assessments of the production function of firms in the staples sectors that centre on its capital intensity and barriers to entry; second are macro-economic studies of the impact of resource booms on the sectoral distribution of investment and labour, and the impact windfall rents have on exchange rates and competitiveness of non-staple exports; third, are empirical correlations between rates of economic growth and dependence on resource exports; and fourth are assessments of the factional, predatory and/or delusional political structures that arise in the rentier economies of resource-abundant states.

Vahabi (2017) makes the useful distinction between economic resource curse literature and political resource curse literature. The basic tenet of the former is that resource rich economies tend to grow more slowly than resource-poor economies (Auty, 1993; Ross, 1999; Sachs and Warner, 1995). The latter focusses more on the tendencies of resource-rich states to be authoritarian, corrupt and prone to civil wars than resource-poor states (Ross, 1999; Collier and Hoeffler, 1998).

There are various theories and concepts to explain the negative economic effects of the resource curse on growth, democracy, and governance. The theoretical literature is dominated by models of rent-seeking behaviour which can have various economic, political and social consequences (Murshed, 2018). Resource-rich economies with capturable resource rents can fall subject to rent-seeking behaviour as revenues and royalties from oil or mineral resources are readily appropriable (Murshed, 2018).[2] Rent-seeking behavior, in turn, can impact economic productivity either through detracting from normal production (Murshed, 2018) or diverting the potential benevolent forces of entrepreneurs towards corrupt rent capture (Torvik, 2002). While resource rents are appropriable, and perhaps more so that other forms of rent, states and other actors have a choice as to how they respond. Political leaders can either undertake benevolent policies or pursue rent-seeking practices. (Auty and Gelb, 2001).

Of course, the experiences of countries with resource wealth have varied enormously. Most resource curse studies are empirical in nature, employ econometric tests to demonstrate to demonstrate the curse as a stylised fact, and report evidence of some type of resource curse (Vahabi, 2017). A much smaller proportion contributions have found against the resource curse thesis (see for example Herb, 2005; Haber and Menaldo, 2011). Critics of the resource-curse theory point to countries that have avoided the curse, such as Botswana, Chile and Malaysia (Lee et al. 2012). In light of this, critics of the resource curse thesis have suggested that underdevelopment in states with large resource endowments is the result of other factors (Clements and Johnson, 2000). These studies assert that mineral resources cannot be said to be the determining factor in low levels of economic development.

[2] Meissner (2010) argues that theories of the rentier state can be subordinated to the overall literature on the resource curse with rents representing the independent variable.

3.2.3.1 Resource curse theory and the cobalt sector

The DRC has been the focus of several studies related to the resource curse. This is not surprising. The country possesses extraordinary mineral wealth and plays a globally significant role in the world's production of cobalt, copper, diamonds, gold, tantalum, and tin (USGS, 2015b). Despite this, its development has been blighted by numerous issues. The country's economic, political and social issues are easily discerned from statistics. GDP per capita (PPP) was estimated at US$800 in 2015 (CIA, 2016) putting the country 226/229 countries measured. The country ranked 147/168 in Transparency International's Corruption Perceptions Index (Transparency International, 2016). And it ranked 176th out of 189 countries on the UNDP 2018 Human Development Index (IMF, 2019).

An IMF study (2019) noted that the DRC has experienced various problems related to the resource curse, including corruption in the management of the resources given large rents, overblown public expectations of the benefits and political pressures to spend the revenues, disputes over revenue allocation, and the lack of technical capacity to manage the resources.

Most studies of the resource curse in the DRC have explored the political resource curse. These typically examine the links between the country's mineral wealth and its issues of bad governance, human rights issues or conflict. With regard to the former, Matti (2010) found that resource rents were instrumental in the entrenchment of patrimonial networks in the Mobutu period and concluded that despite significant changes in the Congolese economic condition, the patrimonial incentive structures established during that period have persisted in the post-conflict period, facilitated by foreign aid inflows (Matti, 2010).

With regard to human rights and cobalt specifically, a number of contributions have investigated the impact of cobalt mining on local communities in the DRC from a human rights (Amnesty International, 2016; Global Witness, 2009; Peyer, 2011) environmental (Scheele et al., 2016; Tsurukawa et al., 2011) and social impact perspective.

With regard to the conflict, Daniele (2011:564) found that "…a fragile institutional context, [and] abundant lootable resources have been used to fuel conflicts and corruption: this has hampered economic development, reinforcing the mechanism of a sort of resource-based poverty trap". Samset (2002) concluded that the motivation and feasibility of resource exploitation largely explains why external military contingents remained active in the country. A study by Guenther (2008), focussing on the impacts of global commodity prices on good governance and peace-building in the DRC, had similar conclusions. The study argued that there is a connection between natural resource dependence, armed conflict and weak governance (Guenther, 2008). Luca et al. (2012) examined whether the DRC government's granting of mineral concessions in particular geographical areas has had an impact on the intensity of conflict. The study found that at the territory level, granting concessions does not affect the level of conflict, while at the district level, the right to exploit mineral wealth exacerbates the level of violence (Luca et al. 2012). Several studies, however, cast doubt on the notion that resources cause of violence in conflict-ridden countries (see for example Brunnschweiler and Bulte 2009; Arezki et al. 2015). These studies argue that there are important and unsupported assumptions regarding how natural resources are linked to the motivations of combatants (Cuvelier et al., 2014,2).

Nonetheless, convinced that the DRC suffers from the resource curse, advocacy groups have successfully lobbied for top-down policies to reduce international demand for Congolese minerals extracted with armed group involvement (Parker and Vadheim, 2017). The primary policy to have had an impact was Section 1502 of the 2010 US Dodd-Frank Act. This was effectively a disclosure requirement forcing US firms to determine whether their products contain conflict minerals by carrying out supply chain due diligence – and to report this to the US Securities and Exchange Commission (Global Witness, 2011). The policy didn't target cobalt but focused on tin, tantalum, tungsten (commonly known as the 3Ts), which are widely produced in the east of the DRC. While many advocacy groups have pointed to the successes of this policy, academic support has been limited. In 2014, 70 academics (2014:1) wrote an open letter arguing that "…despite the successes of activists in shaping policy, the conflict minerals campaign fundamentally misunderstands the relationship between minerals and conflict in the eastern DRC". A study by Parker and Vadheim (2017) found that the decision to regulate conflict minerals from the DRC did not reduce violence committed by militias, with evidence indicating that the policy instead increased the likelihood that armed groups looted civilians, committed violence against them, and turned their attention to gold mines. Stoop et al. (2018) report similar findings, concluding that the legislation strongly and significantly increased the likelihood of violent conflict in affected territories, especially in relatively unregulated gold mining areas.

3.3 Theories of the firm

Theories of the firm consist of a broad range of economic explanations that predict the nature of firm location, structure, relationship to the market and behaviour. Of particular relevance to this research is an understanding of why firms assume certain structural forms and why firms locate where they do.

3.3.1 Firm structure theories

Theories on the structure of the firm can be divided into four distinct but overlapping traditions: transaction cost theory, property rights theory, agency theory and resource-based theory[3] (Barney and Ouchi, 1986; Kim and Mahoney, 2005).

The genesis of the literature on transaction cost theory is generally attributed to Coase (1937). Coase (1937) argued that transactions and processes would be organised *within* the firm when the cost of doing so was lower than the cost of doing so within a market. For example, the costs of constant contracting with an outside firm or manager can be high relative to those of signing a long-term contract with an employee in which the employee agrees to carry out the commands of the employee (Grossman and Hart, 1986). Williamson (1975) further contributed that the properties of the firm that commend internal organisation as a market substitute fall into three categories: incentives, controls, and inherent structural advantages. He supposed that contractual relationships between a separately owned buyer and seller will be plagued by opportunistic and inefficient behaviour (Grossman and Hart, 1986). This behaviour results from the difficulty in writing detailed long-term contracts and leads to an uneven division of control or surplus. Thus, incomplete contracts can cause a non-integrated relationship to yield outcomes that are inferior to those that would be achieved with complete contracts (Grossman and Hart, 1986) and firms are more efficient at solving transaction cost problems than markets (Coase 1937; Peng et al., 2015; Williamson, 1985).

Course (1960) is also generally regarded as the conceptual starting point for property rights theory although the literature has been deepened by many others.[4] While there are considerable overlaps between the property rights framework and other theoretical frameworks of firm structure, property rights theories are particularly concerned with issues of ownership. Grossman and Hart (1986) define the firm in terms of the distribution of ownership of assets and argued that there is often a low-cost alternative to contracts that allocate all specific rights of control. In their view, when it is too costly for

[3] It has been argued that the resource-based view cannot be said to constitute a theoretical system (see Hunt, 1991; McKelvey, 1997; Priem & Butler, 2001).

[4] Kim and Mahoney (2005) make the useful distinction between ‘classical’ rights theory (see for example Demsetz 1967; Furubotn and Pejovich; 1972; North, 1990) and ‘modern’ rights theory (see for example Grossman and Hart, 1986). They assert that the former provides greater attention to historical and institutional contexts that shape property rights, while the latter attempts stylised modelling of ownership and incentive structures.

one party to specify a long list of the particular rights it desires over another party's assets, it may be optimal for the first party to purchase all rights except those specifically mentioned in the contract and thus ownership is the purchase of these residual rights of control (Grossman and Hart, 1986). Thus, firms efficiently allocate resources among the various parties in any transaction.

Agency theory views an agency relationship as a contract which one or more persons (principals) engage another person (the agent) to perform a service on their behalf which involves delegating some decision-making authority to the agent (Jensen and Meckling, 1976). Owing to the fact that agents may not act in the best interests of principals, that governance structures may be required to mitigate the negative impacts on the principal. The principal can limit divergences from his interest by establishing appropriate incentives for the agent and by incurring monitoring costs designed to limit the aberrant activities of the agent (Jensen and Meckling, 1976). Thus, compared to transaction theory which focusses on transactions and contracts, and property rights theory which centres on ownership of assets, the focus of agency theory is more on the individuals involved.

The resource-based view of the firm argues that the source of competitive advantage lies within the boundaries of the firm instead of focussing on a firm’s competitive environment. Here, the concept of resources includes all assets, capabilities, organisational processes, firm attributes, information, and knowledge etc. controlled by a firm that enables the firm to conceive of and implement strategies that improve its efficiency and effectiveness (Barney, 1991; Daft 1993). The resources possessed by a firm are the primary determinants of its performance, and these may contribute to a sustainable competitive advantage of the firm. While resources may result in competitive advantage, those resources that can be easily replicated by competitors will mean that advantages do not endure. Thus, Barney (1991) asserts that resources must be rare and valuable and imperfectly imitable.

Transaction cost and property rights theories, in particular, make the case that as long as it is assumed that there are no additional costs associated with internal organisation, almost any market imperfection necessarily becomes a candidate for creating private incentives for vertical integration (Joskow, 2008). It has also been reasoned that vertical integration is a necessary organisational step in the creation of modern firms through, *inter alia*, the coordination of management practices (Chandler, 1977).

Bucheli (2007) reasoned that vertical integration should also be viewed as a political process, affected by the host country’s social and political dynamics, the relationship between the host country and home country, and the relationship between the firm and the home country. Thus, as well as being an economic and strategic consideration, the vertical integration of extractive companies is the product of complex political and social developments emerging over extended time periods (Bucheli, 2007). This leads neatly to a consideration of where firms choose to locate.

3.3.1.1 Firm structure theories and the cobalt sector

The literature on the theory of the firm provides some useful insights for explaining what has determined the structure of the cobalt chain. In particular, theories on FDI go some way in explaining the emergence of integrated firms spread across multiple jurisdictions. Firm structure has been driven by the desire to bring certain functions and processes within the boundaries of the firm to achieve competitive advantage. The large amounts of FDI in the cobalt sector can be viewed as an attempt by firms to acquire raw materials that are not available domestically.

It is useful to briefly return to the types of firm active in the upstream part of the cobalt sector as outlined in the previous chapter. A distinction was made between integrated type (1) cobalt producers, which both mine cobalt and produce refined cobalt and type (2) producers, which undertake the production of only one form.

Theories of firm structure generally suggest that functions are brought inside the boundaries of the firm when there is a benefit in doing so. The empirical literature on vertical integration is divided into two major areas: contributions that consider the decision whether to integrate forward into retailing and those that examine the "make or buy" decision, which is the decision whether to integrate backwards (Lafontaine and Slade, 2007). In the context of the cobalt sector, mine producers could integrate forward into intermediate or refined production, for example, or refined producers could integrate backwards to secure less-refined cobalt feedstock. Ultimately, extractive sector firms can choose to specialise in one stage of the supply chain (type 2) or diversify across two or more stages (type 1).

Within an extractive sector context, as in the wider literature, vertical integration is considered a strategic, as well as economic, process. Vertical integration enables the realisation of the profits of other parts of the supply chain and can serve to develop a firm's market position through quality improvement, cost reduction, and the shortening of delivery times (Kudelko, 2013). As such, the process can bring about competitive advantage.

Of course, in a sector such as that of cobalt, there are exogenous factors that impact on firm's decisions to bring certain transactions or assets within its boundaries. At the upstream part of the chain, the state plays an important role in this regard. In their capacity as the central resource-holder, able to issue mining licences, states can limit the ability of firms to bring certain assets within their full control. An example of this in the cobalt sector was, until recently, the insistence of the DRC Government to issue a certain amount of control in any extractive operation to the state-owned-enterprise, Gécamines.

3.3.2 Firm location theories

The central question in the literature on location theory where and why economic activity occurs. The overarching logic is that firms chose to base themselves in a certain location based on the economic benefits of doing so. The earliest theories[5] are characterised by perfect competition, homogenous products and non-increasing returns to scale and hold that, assuming no trade costs, the spatial distribution of demand affects patterns of trade but not firm locations (Brülhart, 1998). However, if trade costs are factored in, there is an optimum location for production based on transport costs.

McCann (2009) identifies three distinct sub-traditions in the regional science literature on location theory, stemming from contributions from von Thünen, Weber and Hotelling. In each of these traditions, location is determined by resource endowments and factors together with transport costs. Von Thünen's (1826) work based on agricultural land sought to determine the influence of transport costs on the location of agricultural production. Taking into account the costs of land rent, land yield, production costs, market costs and transport costs, von Thünen concluded that as the distance from land to the market increased it would increasingly be utilised by farmers whose products were cheaper to transport in relation to their value. This work was subsequently adapted to take into account urban contexts (see for example Alonso, 1964). An alternative approach stems from a theory put forward by Alfred Weber (1909) who identified the optimum location for a production site based on the location of the market and two raw materials sources based on the costs of transporting raw materials. In this approach, the weight of the raw material inputs translates to transport costs which determine raw material production. A different view was put forward by Hotelling (1929) who focussed on the interactions between location and competition and contended that if no price competition exists, a stable clustered optimal outcome is possible (McCann, 2009). Hotelling's model of spatial competition suggests that firms can mitigate competition through the selection of a location in an environment where prices are constant.

An important distinction regarding the determinants of location is between what Krugman (1991) termed first nature and second nature elements.[6] The former is concerned with immobile factors of production, such as natural endowments, that constrain the spatial structure of the economy, while the

[5] While Brülhart (1998) calls these neo-classical theories while McCann (2009) refers to these theories as originating from the regional science tradition.

[6] A term appropriated from Cronan (1991).

latter is concerned with the location of agents relative to one another in geographic space, and the role that this plays in understanding spatial disparities (Redding, 2008). Later contributions dispensed with first nature elements and focussed more on the manufacturing sector. The focus of enquiry was understanding why particular industries were concentrated in certain areas. Perhaps the most important early contribution was that of Marshall (1920), whose study of industry location identified three reasons for localisation: locally shared non-tradeable intermediate inputs, a pooled market for skills and workers, and information spillovers. Later theories, specifically 'new trade theory' (NTT) and 'new economic geography' (NEG), factored in monopolistic or imperfect competition and increasing returns ignoring all exogenous, first nature factors (in NEG) expect market size (in NTT) (Brülhart, 2003).[7] Perhaps the seminal work in NEG was Krugman's (1991) study on increasing returns in economic geography, which showed that the emergence of a "core-periphery" pattern depends on transportation costs, economies of scale, and the share of manufacturing in national income. Krugman identified that location choices are determined by a tension between agglomeration forces, which promote the spatial concentration of economic activity, and dispersion forces, which favour an equal distribution of economic activity (Redding, 2008). When transport costs are low, it was shown that manufactures become concentrated in the "core", supplied with raw material inputs by the "periphery".

These models and theories were necessarily built with restrictive assumptions for the sake of simplicity. An issue with all sub-streams of location theory, new and old, is that that they treat the firm as a single point in space whereas many firms are very different in nature, particularly multi-plant and multi-national firms (McCann, 2009). Thus, these models are only somewhat useful in explaining what determines the locational choices of many firms operating in today's global economy.

With regard to multi-national firms, taken to mean firms with assets in at least two countries, it has been reasoned that their strategies are centred on tapping location-bound resources in order to improve their comparative advantage over a non-internationalising competitor (Porter, 1994). Thus, advantage is developed through the process of internalisation (Buckley and Casson, 1976) and is only gained when the benefits, or internal advantages, outweigh the relative cost entering a second territory (Hymer, 1976).

Several contributions have sought to identify the determinants of foreign direct investment (FDI), taken to mean an investment in the form of a controlling ownership in a firm in one country by an entity based in another country, and generated theories. These include a motivation to achieve higher returns in foreign markets through lower labour costs and exchange risks; ownership benefits, economies of scale

[7] For an overview of the theoretical literature on NEG see Baldwin et al., (2002).

and incentives; and oligopolistic and behavioural drivers based on following competitors into foreign markets.[8]

Of particular interest is Dunning's (1988) "eclectic" or "ownership, location, and internalisation (OLI)" approach, which suggests three advantages that can underpin a firm's decision to become multi-national. Ownership advantages refer to the benefit of owning tangible and intangible firm assets which can lead to higher profitability than at other firms, such as patents or technology. Location advantages refer to economic, institutional and social advantages gained from activity in a specific location which can boost profitability, such as lower costs or taxes. Internalisation advantages refer to benefits achieved through owning rather than licensing from or collaborating with other firms, which underpins decisions on the structure of the foreign entity.

Further research from Dunning (1993) identifies four motivations for FDI: resource seeking, market seeking, efficiency-seeking and strategic asset seeking. The first is concerned with a firms desire to acquire resources that are not available domestically or are lower cost in the new location. The second, market seeking, refers to a desire to exploit new or larger markets. Efficiency seeking refers to achieving a better division of labour or specialisation etc. Strategic asset seeking refers to the acquisition of new assets external to the firm.

3.3.2.1 Location theories and the cobalt sector

Theories of firm location centre around explaining why particular industries are concentrated in certain areas. With regard to cobalt and other extractive sectors, it is an obvious but important point that at the upstream part of the chain (mining) firm location is dependent solely on the availability of economic concentrations of cobalt ores. As is the case with other extractive sectors such as oil, new reserves are found only in specific locations, which imposes some limits on the spatial flexibility of the upstream end of the production chain (Bridge, 2008). Thus, first nature elements, immobile factors of production such as natural endowments that constrain the spatial structure of the economy, are important. While in pure economic terms the optimum location for a cobalt mine could be said to be close to the market for its output, ignoring environmental concerns and alike, the paucity of cobalt deposits means that access alone is the first consideration. Thereafter, the logic of rent capture suggests that firms compete for access to cobalt resources that will yield the most rent.

[8] For an overview of key contributions see Assunção, et al. (2011).

But why do a high concentration of downstream (refined cobalt producing) firms operate in different locations to the source of extraction? At the downstream part of the chain, second nature elements play a more important role. More recent theories of firm location may provide some clues. Certainly, it can be said that the core-periphery model fits well with observations of the cobalt sector. Refined cobalt production can be said to be concentrated in the "core", in this case China, Europe and North America, supplied with raw material inputs by the "periphery", in this case the DRC. Thus, at the downstream part of the cobalt chain, locations are likely determined by tensions between agglomeration and dispersion forces.

An issue with location theories is that they treat the firm as a single point in space. Like most sectors today, this is not reflective of the cobalt sector. The high level of FDI in the upstream part of the cobalt sector is evident. By way of an example, the biggest mine producers of cobalt in the DRC are controlled by Glencore (based in Switzerland) and China Molybdenum (based in China). Using Dunning's (1993) framework for explaining the motivations of FDI, these firms have, in particular, been driven by a desire to acquire resources that are not available domestically. Thus, they have tapped location-bound resources in order to improve their comparative advantage over a non-internationalising competitor (Porter, 1994). This represents a decision to try to benefit from internalisation, through owning rather than licensing from or collaborating with other firms, which underpins decisions on the structure of the foreign entity. This produces differential rent that can be captured by firms via property rights as firms holding large, low-cost reserves are able to obtain maximum rents as a result of their spatial monopoly (i.e. ability to exclude) other firms (Bridge, 2008).

The global nature of the cobalt supply chain highlights the limited explanatory capacity of theories and models that restrict the firm to a single point in space. Neoclassical theories, therefore, are of little use for explaining the emergence of multi-national firms engaged in FDI in the cobalt sector. Theories incorporating the process of internalisation are more useful. In particular, the notion of resource seeking, where firms seek to acquire resources that are not available domestically, is highly applicable. At the upstream part of the cobalt sector, firms have entered into arrangements with states, in their capacity as resource holders, to gain access to cobalt resources. The geological embeddedness of mineral resources in nation-states, distinguishes primary sector chains from manufacturing and service sector chains. Metals such as cobalt are territorially embedded in the proprietorial, institutional and cultural-political structures of the nation-state (Bridge, 2008). At the mining and extraction (upstream) end of the chain, cobalt is owned by the state. The cobalt raw materials that firms require are, therefore, not owned by these firms but controlled via arrangements enacted by states. As such, states play an unusually strong role in extractive production networks, as government decisions and state policies around resource ownership and access can, it logically follows, produce large-scale changes in the configuration of the network (Bridge, 2008).

3.4 Global chains and production networks

Globalisation has been widely discussed and defined. Broadly speaking, it can be considered as a set of economic, social, technological, political and cultural structures and processes arising from the changing character of the production, consumption and trade of goods and assets that comprise the base of the international political economy (UNESCO, 2001). The global expansion of economic activities has been driven, *inter alia*, by the practice of economic agents (business enterprises, banks, and finance companies), working in different countries and serving the world market without a prevailing national base, changing their location between national territories on the basis of opportunities for growth and profit (Gaburro and O'Boyle, 2003). The increasing might of transnational corporations (TNCs) has shifted power away from the nation-state, making firms perhaps the dominant economic actor in the global economy. Their rise, and the globalisation of economic activity, has been underpinned by processes such as privatisation, liberalisation, and deregulation, and via developments in technology, communication and transport (Neal, 2012).

Global production has become organisationally fragmented and spatially dispersed (Dicken, 2011). Global production networks and global value chains can now be considered the most critical organisational platforms through which production in primary, manufacturing and service sectors is coordinated and organised on a global basis (Yeung and Coe, 2015). The global economy is characterised by global value chains in which intermediate goods and services are traded in fragmented and internationally dispersed production processes (UNCTAD, 2013). These chains, which account for 80% of global trade, are typically coordinated by TNCs, with cross-border trade of inputs and outputs taking place within their networks of affiliates, contractual partners and arm's-length suppliers (UNCTAD, 2013). While firms, especially TNCs or *lead firms,* are then perhaps the dominant economic actor, since the 1990s, there has emerged the view that the route to competitive advantage lies through the supply chain and that the unique set of relations that typify the web of interconnections between organisation in a network enable the achievement of competitive advantage through lower costs and, or, greater differentiation (Christopher and Towill, 2002). Put more succinctly, supply chains compete, not companies (Christopher, 1992). Understanding how global chains are formed, organised and driven, is essential to understanding the actors and processes that shape the global economy, and the geographies of supply chains.

3.4.1 Global chains

One way to understand the relationship between the actors and activities involved in creating goods and services in the global economy is to describe them as links in a commodity chain (Bair, 2009). The notion of a commodity chain was introduced in Wallerstein's *The Modern World System* (1974) and was, itself, an extension of dependency theory (Raikes et al. 2000).[9] Hopkins and Wallerstein (1977, 1986) further introduced the concept of commodity chains, defining them as a network of labour and production processes whose end result is a finished commodity. Their research, rooted in world-systems theory, sought to distance itself from the conceptualisation of global economic development as a sequential process and instead begin with…

> "…a radically different presumption. Let us conceive of something we shall call, for want of a better conventional term, 'commodity chains.' What we mean by such chains is the following: take an ultimate consumable item and trace back the set of inputs that culminated in this item, including prior transformations, the raw materials, the transportation mechanisms, the labour input into each of the material processes, the food inputs into the labour. This linked set of processes we call a commodity chain. If the ultimate consumable were, say, clothing, the chain would include the manufacture of the cloth, the yarn, etc., the cultivation of the cotton, as well as the reproduction of the labour forces involved in these productive activities" (Hopkins and Wallerstein ,1977, p.128).

Thus, in Hopkins' and Wallerstein's view, a commodity chain is the outcome of various interlinked processes connecting actors and activities across space. Commodity chains represent the "…warp and woof" of the system of social production in the capitalist world economy (Hopkins and Wallerstein, 1994, p.7) linking together the firms and processes dispersed across territories since the modern world economy's inception in the sixteenth century (Wallerstein, 2000). Importantly, according to Hopkins and Wallerstein, the spatial and social configurations of chains are linked to cyclical shifts in the world economy, with contraction of the global economy prompting the reduction of the geographical scope of the chain (as the number of actors falls), while the vertical integration of the chain (the incorporation of more links of the chain into the organisational boundaries of the firm) tends to increase at such a time (Hopkins and Wallerstein, 1994; Bair, 2009). Another geographically relevant result of long-term

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[9] There is also considerable crossover with other overlapping bodies of work such as *commodity systems analysis* (Friedland, 1984) *systems of provision* (Fine and Leopold, 1993) *commodity circuits* (see Hughes and Reimer, 2004) and the *filiére approach* (see Raikes et al. 2000), all of which describe production and consumption processes using a chain metaphor. However, it has been argued that Friedland's work made no reference to Wallerstein and vice versa and that these are distinctly different traditions in their conceptual drivers, objects of study and modes of analysis (Jackson et al., 2006).

economic cycles is that the spatial distribution of linkages changes over time with the demonopolisation of highly profitable processes being brought about by technological change and/or redefinition of organisational boundaries changing the geographies of the chain over time (Raikes et al. 2000).

3.4.2 Global commodity chains and global value chains

It was Gary Gereffi (1994) who introduced the notion of the global commodity chain in his contribution to *Commodity Chains and Global Capitalism*. Gereffi (1994) identified three dimensions of global commodity chains for analysis: an input-output structure; territoriality; and governance.[10] The first describes the transformation of inputs into products; the second geographical configuration; and the third describes the processes by which actors exert control over other participants and how the *chain drivers* (lead firms) appropriate or distribute value that is created along the chain (Bair, 2009). It is this last dimension that has received the most attention in the literature. While grounded in the world-systems tradition of commodity chain research, the global commodity chain approach departed somewhat from the former through its increased focus on the activities of firms, especially lead firms, as opposed to the state; "core-periphery" inter-firm networks linking developing-country exporters to world markets; and through mostly neglecting investigation of the cyclical dynamics of commodity chains (Bair, 2009).

When attempting to understand the processes that shape the structure and geographies of certain chains, the global commodity chain approach is useful. The approach allows for examination of the processes and structures that connect actors across space and emphasises the role of power. Gereffi (1994) makes the distinction between "buyer-driven" and "producer-driven" commodity chains. The first variant refers to chains driven by large MNCs/TNCs in the technology and engineering sectors. Such firms in the "core" gain a competitive edge through innovations that transfer competitive pressures to peripheral areas of the world economy. The buyer-driven global commodity chain variant refers to large retail firms, for example, which help to create, shape and coordinate the chains that supply their products (Sturgeon, 2009). This idea that lead firms could define and shape the global commodity chains fits well with the experience of many developing countries which have become integrated into the world market as exporters through their light manufacturing industries (Bair, 2009).

A related approach is the global value chain. This has both been conceived of as a concept interchangeable with global commodity chains (Daviron and Ponte, 2005) and a broader intellectual project with its own agenda and theory of governance (Sturgeon, 2009). Those that eventually sought

[10] In a subsequent publication, Gereffi (1995) added a fourth dimension, institutional context.

a distinct global value chain analytical framework had encountered difficulty in assigning field research findings into a static "buyer-driven" and "producer-driven" global commodity chain framework, seeing instead a shift towards external networks and changing governance relationships (Sturgeon, 2009). In particular, increased outsourcing in what would be traditionally be seen as "producer-driven" global commodity chains became evident, prompting calls for calls for a more dynamic framework of chain governance. A further limitation of the global commodity chain approach was the underdeveloped geographical conceptualisation, given its focus on national scale analysis, as well as its underdeveloped territorial component, illuminated by an inability to delimit the ways in which firm networks link together (Coe and Yeung, 2015).

In a paper that emerged from the deliberations of the global value chain initiative (Gereffi et al., 2005), five distinct governance structures (markets, modular, relational, captive and hierarchy) influenced by three core variables (complexity of transactions, codifiability of information and the capabilities of the supply base) were put forward. Through this move to focus more on inter-firm governance, the global value chain approach successfully addressed some of the limitations of the global commodity chain framework. Nonetheless, the global value chain approach, too, underplayed the extent to which governance is influenced by geographically specific conditions and firm and non-firm dynamics (Coe and Yeung, 2015).

3.4.3 Global production networks

Another way of understanding the relationship between the actors and activities involved in creating goods and services in the global economy is through the concept of a network. Put simply, such an approach conceptualises the ways in which actors (referred to in the literature as nodes) are connected via processes (edges or links). As such, a network approach is multi-dimensional in a way that the global commodity chain and global value chain frameworks are not.

While network approaches to international trade analysis have been commonplace among economists over recent years, there have been relatively few analyses of trade by economic geographers.[11] Nonetheless, network approaches have become a major analytical concept in economic geography, used to extend both empirical and theoretical research agendas (Vorley et al., 2012). Network approaches have been applied to geography for some time (see for example Haggett and Chorley, 1972) although it is only recently that economic geographers have used the network as a major analytical tool to explore

[11] Krugman (2009) goes some way to explain how and why the fields of geography and international trade have remained separate.

the socialised aspects of economic behaviour (Vorley et al., 2012). The increased application of network approaches has coincided with the growth of *relational* approaches in economic geography which have grown in popularity and brought about increased focus on network relationships between actors.

At its most specific, the term *relational* is used to refer to a specific mode of economic coordination or governance that is based on strong ties and long-term, reciprocal relationships although as Sunley (2008) asserts, relational economic geography remains more a loose assembly of theories and ideas than a carefully defined analytical framework.[12] The relational turn in economic geography has brought about a rich body of literature in which relations, networks, and interconnections of all types have been explored to further understanding of the global economy. These approaches naturally lend themselves to understanding global supply chains and it is unsurprising that a number of contributions have explored the production, distribution and consumption of goods and services (Coe et al., 2008).

A relational understanding of economic globalisation was first put forward by Dicken et al. (2001), based upon elements of Actor-Network Theory. A more formal conceptualisation was introduced by Henderson et al., (2002), who presented a broad relational framework distinct to the global commodity chain framework. These contributions can be considered the genesis of a global production network perspective.

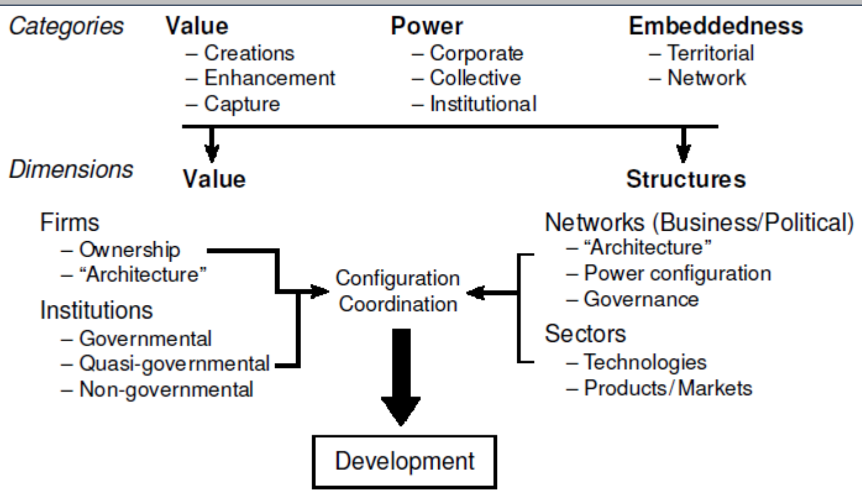
While the global commodity chain approach outlined above focussed on governance processes that drive production, consumption and trade, global production network thinking encompasses a focus on the key actors involved. In the first book-length analysis of the global production network approach, a global production network is defined as an organisational arrangement, comprising interconnected economic and non-economic actors, coordinated by a global lead firm, and producing goods or services across multiple geographical locations for worldwide markets (Coe and Yeung, 2015). A global production network approach, therefore, focusses on the numerous geographies bound together by the economic relations born of actor-specific firm and non-firm strategies. In doing so, the global production network approach attempts to overcome the most common critique of global commodity chain and global value chain frameworks, namely their emphasis only on vertical relations in the coordination of economic activity (Henderson et al., 2004; Patel-Campillo, 2010). It, therefore, addresses the reality that production chains are embedded in linear/vertical as well as non-linear/horizontal relationships (Coe et al., 2008; Patel-Campillo, 2010).

[12] Sunley (2008) goes on to show how actor-network theory, and its emphasis on the construction of diverse, heterogeneous networks involving both human and non-human actants, as well as artefacts, techniques and technologies has given further impetuous to the relational turn in economic geography. According to actor-network theory, capitalism is constituted by financial and economic commodity networks (see Leyshon, 1998).

Four key factors distinguish the global production network approach from those discussed above (Coe and Yeung, 2015). First, thorough consideration of extra-firm networks, it brings in a range of non-firm actors. Second, the approach considers all spatial scales from local to global. Third, it moves beyond the chain approach, focusing on *network* structures which are arguably more reflective of the structures that underpin the global economy. Fourth, it improves upon earlier analyses of how governance is shaped by geographically diverse regulatory and institutional contexts. It, therefore, goes some way to incorporate the complex actions and interactions of a variety of institutions and interest groups – economic, political, social, and cultural – which operate at multi-scalar levels and territorialities and through dynamic and asymmetrical power relationships to produce specific geographic outcomes (Coe et al., 2008). Put simply, it is more capable of grasping the global, regional and local, economic and social dimensions of the processes involved in many (though by no means all) forms of economic globalisation (Henderson et al., 2004). In the aforementioned book-length global production network overview, the initial global production network framework, as produced by Henderson et al. (2002), is termed GPN 1.0[13] and is presented in Figure 9 in the form of a schematic.

Figure 9: GPN 1.0

A schematic representation of GPN 1.0



Source: Henderson et al., (2002)

GPN analysis seeks to explain the nature and organisation of global production networks, which involve both capitalist firms and diverse economies in organisationally complex and geographically extensive

[13] Coe and Yeung (2015) make the distinction between GPN 1.0 which set out the initial framework, and more recent work termed GPN 2.0, which engages in a theoretical development of the framework to extend the explanatory power of GPN 1.0.

ways (Coe and Yeung, 2015). As shown in Figure 9, the global production network framework denotes three interrelated variables used to explore the configuration and coordination of GPNs by firm and extra-firm actors – value, power and embeddedness:

- Value pertains to both surplus value created through the process of production which converts labour power into more valuable products, and the economic rent that can be realised through transactions in a GPN in various ways. GPN thinking is concerned with how actors create, enhance and capture value.

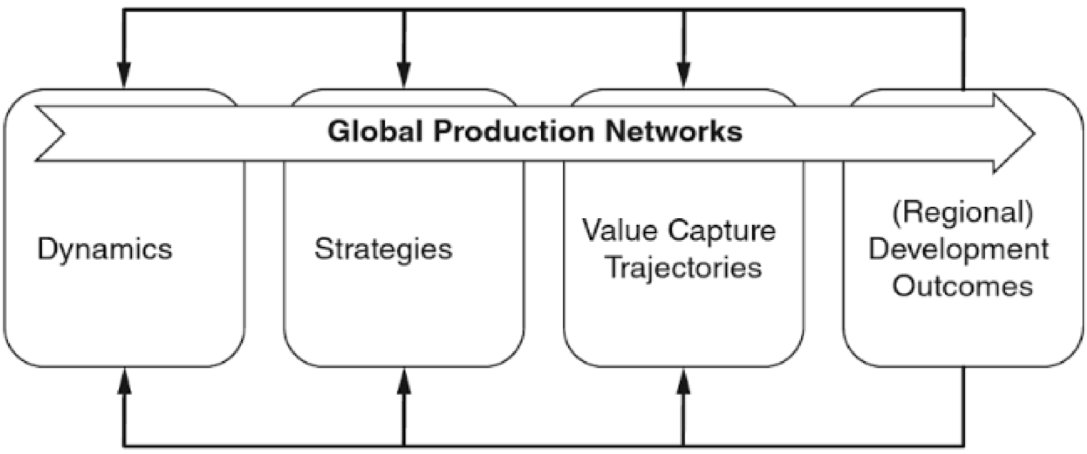
- Power refers to the ability of an actor to influence another to the detriment of the latter. The GPN framework encapsulates corporate power, collective power (labour, unions etc.) and institutional power (e.g. international institutions). Power is seen as relational and transaction specific, varying between actors and their resources.

- There are two interrelated forms of embeddedness employed within GPN thinking. Territorial embeddedness refers to how actors are located in different spaces. This is because of an actor's dependence on resources, materials, labour etc., located in particular places. Coe and Yeung (2015) note that a key element of territorial embeddedness is the extent and nature of the relationships formed between firms performing different roles within networks. Network embeddedness is concerned with network structure and the connectivity within a GPN.

Critics argued that the early GPN conceptualisation was not sufficiently explanatory and causal to provide a coherent understanding of global production networks. Put simply, it does not constitute a theory. Thus, recent work (Coe and Yeung, 2015) has focused on uncovering the causal links that connect through from the structural dynamics that underpin global production network formation and operation to development outcomes for regional development.

Figure 10: GPN 2.0

A theoretical schema of GPN 2.0



Source: Coe and Yeung (2015)

Dynamics refer to underlying capitalist dynamics such as markets and risk and represent the imperatives of the global economy. These are the key factors that shape the strategies of global actors in conjuring global networks in their pursuit of capturing value and ultimately the developmental outcomes of industries, regions and countries (Coe and Yeung, 2015). The black arrows in the figure above highlight how this isn't intended to be an overly deterministic theory, with feedback mechanisms between the various elements.

The global production network approach has been applied to a range of sectors (see Murphy and Schindler, 2009; and Patel-Campillo, 2010). Of particular relevance to this dissertation is the work of Bridge (2008) who outlined the key actors and relations of the global production network of oil. Bridge expanded the more traditional, linear, view of the hydrocarbon supply chain into a global production network of inter-firm and firm-state relations that linked the various actors of the supply chain together and revealed a number of relations not captured by the linear commodity chain. Generally speaking, though, the extractive industries have not been central to the GVC and GPN intellectual projects (see however, Bridge and Bradshaw, 2016; Dicken, 2015; Gibson and Warren, 2016; MacKinnon, 2013; Steen, and Underthun, 2011). Certainly, there have been no examinations of critical materials, with the aforementioned contributions focusing on energy (Bridge, 2008; Dicken, 2015; MacKinnon, 2013; Steen, and Underthun, 2011), base metals (Dicken, 2015; MacKinnon, 2013) and timber (Gibson and Warren, 2016).

Another highly relevant example is the work of Gibson and Warren (2016) who showed the value of exploring nature-facing elements of GPNs, and how these evolve temporally in response to certain factors related to regulation and concerns over material provenance. Gibson and Warren (2016) advocated the analysis of what they termed “resource-sensitive GPNs” where upstream processes and actors linked to input resources and manufacturers are bound into deepening relationships with consumers in novel ways. Through their study of timber for acoustic guitar manufacturing, they found that as regulation produced new resource supply security risks, actors in resource extraction, procurement, and regulation emerged, consolidated expertise, and influenced downstream global networks dependent on those input materials.

3.4.3.1 Strategic coupling

A primary motivation of the GPN approach is to provide a framework for explaining patterns of uneven economic development in the global economy. Global production network analysis posits that the key locus for understanding economic development is the sub-national region, as actors are grounded in particular places, not national economies, which have distinctive institutional conditions that shape development practices and processes (Coe and Yeung, 2015). GPN thinking argues that economies of scale and scope embedded within specific regions are advantageous to those regions, and bring about regional development, only insofar as such region-specific economies can complement the strategic needs of lead firms in global production networks (Coe and Yeung, 2015). It is held that when such a complementary effect exists between regions and GPNs, a developmental process of *strategic coupling* will take place through which the advantages of regions interact positively with the strategic needs of actors in the GPN (Coe and Yeung, 2015).

The concept of strategic coupling refers to the dynamic processes through which actors in cities and/or regions coordinate, mediate, and arbitrage strategic interests between local actors and their counterparts in the global economy (Yeung, 2009). The concept is used to explain the process of how a regional economy, or regional actors, integrate themselves into GPNs in a mutually beneficial way. Strategic coupling can be defined as a “…mutually dependent and constitutive process involving shared interests and cooperation between two or more groups of actors who otherwise might not act in tandem for a common strategic objective” (Yeung, 2009: 332).

The strategic coupling process has three important characteristics (MacKinnon, 2013; Dawley et al., 2019). The first is that it is viewed as strategic since it relies on intentional action and active deliberation by participants (MacKinnon, 2013; Dawley et al., 2019). This relates to the agency of the actors in question, namely regional institutions such as state agencies, labour organisations and business associations which engage in bargaining and cooperation with GPN actors such as lead firms (Coe and

Yeung, 2015). It raises interesting questions surrounding how agency differs between actors, changes temporally, and is shaped by context, norms and institutional structures and settings (Dawley et al., 2019). Processes also depend critically on power, bargaining and co-operation relationships between regional institutions and GPN actors (Yeung, 2015).

The second is that it is time and space contingent, involving the construction of a 'temporary coalition' in the pursuit of a common objective between groups of actors who might not otherwise work together (MacKinnon, 2013; Dawley et al., 2019). Put simply, actors such as firms and institutions engage together in perceivably mutually beneficial activities which serve their interests. Such temporary coalitions can be very short lived, and can range in their depth or scale, resulting in cooperation at a certain time without that leading to enduing economic collaboration between actors (Phelps and Wood, 2006). For this reason, MacKinnon (2012) goes beyond the idea of strategic coupling and introduces a wider range of coupling processes such as recoupling and decoupling that take place between regions and GPNs. Further to initial strategic coupling, institutions and GPN actors can decide to recouple through repeat investment or not.[14] Kleibert (2013: 257) agrees that coupling processes are dynamic and the roles of actors do not remain fixed over time, while also noting that the initial despite the potential brevity of strategic coupling, the initial coupling process can require concerted and planned effort by institutional actors to create a linkage. Importantly, coupling, recoupling and decoupling could be relatively effortless or require considerable exertion, depending on the content and the actors involved. Put another way, it is not automatic and not always successful (Coe et al., 2014; Yeung, 2015).

The third key concept of strategic coupling is that it transcends territorial boundaries, bringing together actors who operate across different spatial scales (MacKinnon, 2013; Dawley et al., 2019). Like GPN thinking more broadly, strategic coupling considers the multi-scalar levels and territories in which actors engage. GPN research stresses that many of the critical strategic decisions that shape coupling processes within regions are made by extra-regional actors such as lead firms, national governments and supra-national authorities (Dawley et al., 2019: 858).

[14] Early critiques of contributions on strategic coupling argued that it failed to take account of subsequent changes and temporal dynamics. Yeung (2015: 3) however argues that the concept's critics misunderstood its changing and multidimensional nature and misattributed to it a one-way flow of articulation (i.e. coupling does not allow for decoupling or recoupling). Consensus is now that strategic coupling is not what Yeung (2015:6) terms a "…static equilibrium concept".

Thus, strategic coupling brings into question the priorities of GPN actors and institutions, together with their agency and capabilities at any given point in time. Some contributions have explored what they term the 'dark side' of strategic coupling (see Coe and Hess, 2011; Dawley, 2011; MacKinnon, 2012).[15] This term refers to the negative consequences of power asymmetries between partners and includes corporate capture of regional institutions and the negative impacts of corporate restructuring, stemming from power asymmetries favouring firms (Rutherford et al. 2018). It has been argued that GPN analysis has tended to under-play the tensions that arise from the differential powers of agents and institutions, despite the fact that the often unequal nature of the relations between firms and local residents and communities was a central theme of earlier political economy approaches to regional development (Dawley, 2011; MacKinnon, 2012). MacKinnon (2012) argues that situations characterised by unequal power relations and external dependence may be better termed as 'structural coupling', using the example of regions with relatively generic regional labour assets having relatively little bargaining power with lead firms. By way of an example, Yeung (2015:10) outlines how in emerging regions such as Penang and Selangor (Malaysia), Greater Bangkok (Thailand), and Yangtze and Pearl River Deltas (China), the lack of indigenous technological capabilities and lead firms has compelled these regions to take the low road to industrialization and GPN coupling.[16]

Like many other concepts in economic geography, concepts of strategic coupling have been informed by the experiences of manufacturing and service-orientated regions in developed countries (MacKinnon, 2013). However, one contribution (MacKinnon, 2013) of particular relevance to this research discusses strategic coupling in resource dependent economies. This is particularly useful as while GPN studies of resource industries have extended understanding of network configurations and development outcomes, processes of strategic coupling have attracted far less attention (Dawley et al., 2019).

[15] Yeung (2015) also notes how neglect of the 'dark side' of strategic coupling was a common critique of strategic coupling literature and asserts that it is a dimensional, strategic combination of mutual interests and proclivities by key actors in regional economies in GPNs which can be subject to contradictory pressures and competitive tendencies.

[16] While acknowledging the unequal power relationships and tendencies towards structural dependency that lead MacKinnon to use the term 'structural coupling', Yeung (2015) contests that this mode of coupling remains strategic in nature as to engage GPN actors the host state at both national and regional levels has to develop proactive policies and strategies to attract the location of global production that might otherwise go elsewhere.

The study, focusses on the Pilbara region in the north-west of Western Australia, which is rich in iron ore, and concluded that the notion of strategic coupling provides only limited analytical purchase on regional development in the region (MacKinnon, 2013). It was instead argued that the relationship between GPNs and regional assets was more akin to structural coupling (MacKinnon, 2012) in terms of its partial and asymmetrical nature, with crucial inputs such as labour and materials being supplied largely from outside the region.[17]

Nonetheless, MacKinnon (2013) outlines some insights into the operation of regional development processes in resource economies, citing the extroverted nature of development, the limited degree of local economic linkages, the key role of the state, and the unequal power relations between local communities and mining TNCs. He argues that this underlines the enduring relevance of some long-standing themes of geographical political economy such as external domination, uneven development, conflicts over value and the distinction between development 'of' a region and development 'in' a region (MacKinnon, 2013).

MacKinnon (2013) argues that in the context of GPN research, there is a need for further empirically grounded work on regional development issues in resource economies so as to develop a broader perspective on strategic coupling that is informed by a range of sectoral and spatial contexts. This is discussed further in the subsequent discussion of strategic coupling in a cobalt sector context (chapter 5.3.5) and in the conclusion. Other recent contributions have called for continued research on regional initiatives in GPN research to provide a nuanced understanding of the agency of regional institutions (Dawley et al., 2019: 869); more attention to be paid to power relations and asymmetries; and an extension of the temporal component of analysis (MacKinnon, 2012; Dawley et al., 2019).

3.4.3.2 Global production networks and the cobalt sector

GPN thinking would consider the cobalt supply chain a network of connected economic and non-economic actors, co-ordinated by a global lead firm, and producing goods or services across multiple geographical locations for worldwide markets.

Framing the cobalt sector through recent attempts (Coe and Yeung, 2015) at theorisation of global production networks suggests the following: Dynamics such as costs, markets, finance and risk, the imperatives of global capitalism, are the variables that underpin strategies by actors involved in the

[17] This distinction could be termed semantic. Yeung (2015) for example argues that structural coupling is still strategic (see previous footnote).

sector. Through responding to various dynamic pressures and incentives, these actors conjure global networks to create, enhance and capture value. Such processes ultimately shape the developmental outcomes of the sector and the regions in which it touches down.

Thus, using a firm such Glencore (the world's biggest cobalt producer and doubtless a 'lead firm' by the definitions set out in the literature on global production networks) as an example – motivated by these imperatives it seeks strategies to configure the network to its advantage. In the case of Glencore, this is through ownership of assets and inter-, intra- and extra-network relationships (with the governments of Australia, Canada, the DRC, Norway and Zambia, and other firms and stakeholders etc.). Such configurations are how Glencore captures the gains of enrolment in the network. The regions in which Glencore touches down complement the strategic needs of that lead firm (in this case cobalt units). Glencore, thus engages in bargaining and cooperation with regional institutions and others in host countries. This, in turn, has developmental outcomes.

The literature on global production networks specifies that there can be several lead firms in a network. Coe and Yeung (2015, p.39) note that a lead firm should be clearly identifiable within a particular industry which may be characterised by the existence of multiple lead firms. Examples of lead firms in the automotive sector are Volkswagen and BMW. Information technology examples are Apple and Google.

As well as Glencore, Huayou Cobalt, the world's largest cobalt refiner, is undoubtedly a lead firm. As shown in the case study in chapter 7.2.1, when it began operating in 2002, Huayou Cobalt was engaged in only one stage of the cobalt supply chain (refining). But through a series of investments, the company integrated backwards, investing in DRC cobalt mine and intermediate production facilities to bring the production of cobalt feedstock within the boundaries of the firm. It has also started recycling cobalt for the same reason. More recently, the company has moved to integrate forwards and produce lithium-ion battery precursors and cathodes rather than sell its refined cobalt products to external firms. Huayou Cobalt appropriates and distributes value along the chain through mining cobalt in the DRC (or buying it from artisanal miners) and shipping it for conversion into a higher-value product in China.

It could be argued that there are several other lead firms in the cobalt GPN. Those listed below represent TNCs that are involved (directly or through strategic investment) in cobalt mining, refining, trading and consumption.

Table 6: Lead firms in the cobalt GPN

Firm	Domicile	Cobalt assets
Guangdong Dowstone Technology	China	China, DRC
ERG	Kazakhstan	DRC, Zambia
Glencore	Switzerland	Australia, Canada, DRC, Norway, Zambia
Huayou Cobalt	China	China, DRC
Jinchuan Group	China	China, DRC
Nanjing Hanrui	China	DRC, China
Nornickel	Russia	Finland, Russia, South Africa
Sherritt International	Canada	Cuba, Canada, Madagascar
Sumitomo Metal Mining	Japan	Japan, Indonesia
Umicore	Belgium	Belgium, Canada, China, France, Japan, Philippines, USA
Vale	Brazil	Canada, Indonesia, New Caledonia, UK
Source: Author's construction		

3.5 Derivation of research questions

The review of the literature on resource scarcity in chapter 2 outlined more than two centuries of debate on the implications of mankind's dependence on certain finite resources. It showed how this rich history of discourse has evolved, with input from academic, industry and governmental communities, into today's studies on critical materials. And it argued, that while there have been numerous contributions focussed on critical material definition and classification, there have been few that have sought to explore the dynamics that underpin critical materials sectors and understand the causal mechanisms that shape the behaviours of the key actors involved, and the spatial and structural outcomes that occur.

Chapter 3, therefore, explored existing literature to understand what we know about raw material supply chains and the processes and actors within them. The chapter outlined three core bodies of literature with theories to explain *how* and *why* global supply chains are formed and organised. The Chapter considered, in brief, the literature's key concepts and theories in light of the cobalt sector.

Focussing on the 2007 to 2017 period, the aim of this research is to determine how the cobalt supply chain is structured and organised, how its structure and organisation have evolved temporally and geographically, how firms and states have responded to cobalt's criticality (supply risk and demand growth), and how these responses have resulted in spatial and structural outcomes. The research aims to identify the behaviours that have shaped various outcomes in the cobalt supply chain, as well as the outcomes themselves.

To meet this research aim, four research questions are posed as shown below. For each of these questions, hypotheses have been formulated based on the findings of chapter 2 and chapter 3. These hypotheses represent basic suppositions of *how* the cobalt sector ought to be structured, and which factors ought to have shaped its development, based on the literature and observations of the cobalt sector.

RQ1: How is the cobalt supply chain structured and coordinated?

Hypothesis: The cobalt supply chain is a network of connected economic and non-economic actors, co-ordinated by a global lead firm, and producing goods or services across multiple geographical locations for worldwide markets.

The literature on global production networks presents said networks as an "organisational arrangement, comprising interconnected economic and non-economic actors, co-ordinated by a global lead firm producing goods or services across multiple geographical locations for worldwide markets (Coe and Yeung, 2015). For the purposes of this dissertation, this definition was reframed into a basic hypothesis. Testing this hypothesis on the cobalt sector case study allows for a testing of whether the global production network approach fits a critical material setting.

RQ2: How has the spatial structure of the cobalt sector changed over time?

Hypothesis: The geographies of cobalt trade will have altered over time as countries without cobalt resources seek to access to cobalt units, yet retain their core-periphery basis defined, in part, by geology.

Given cobalt's territorial embeddedness in certain states, it is not expected that the geographies of the sector will have changed radically as only certain states can serve as exporters. It is expected countries without cobalt resources will have sought to ensure access to cobalt units by diversifying their supply chains and increasing their imports. Thus, some changes are expected over time.

RQ3: How have firms responded to supply risk and economic importance?

Hypothesis: Firms will have engaged in resource-seeking and foreign direct investment (FDI)

Resource seeking (where firms seek to acquire resources that are not available domestically) is probable given cobalt's criticality and thus it is expected that FDI would have increased as firms attempt to acquire raw materials that are not available domestically. This would mean entering into arrangements with states, in their capacity as resource holders, in able to gain access to cobalt resources.

Hypothesis: Firms will have vertically integrated both forwards and backwards

The literature on vertical integration is divided into two major areas: contributions that consider the decision whether to integrate forward into retailing, and those that examine the "make or buy" decision, which is the decision whether to integrate backwards (Lafontaine and Slade, 2007). It would be expected that increased vertical integration would occur as firms try and integrate backwards, bringing supply of feedstock within the boundaries of the firm, or integrate forwards, bringing the production of higher-value cobalt products within the boundaries of the firm.

RQ4: How have states responded to supply risk and economic importance?

Hypothesis: Resource-holding states will have undertaken resource nationalist approaches in order to capture value from the cobalt sector.

States play important roles in the cobalt supply chain including facilitator, producer, regulator and buyer. Resource-holding states are able to secure economic rents from their natural resource endowments and must decide how best to do so. The government of the DRC, the world's main source of cobalt, is often cited as having implemented resource nationalist policies (James, 2018) and it is hypothesised that various instances of resource nationalism related to the cobalt sectors can be identified.

Hypothesis: Resource-seeking states have created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value from the cobalt sector.

States without resources must decide whether the issue needs to be addressed through state action. It is anticipated that cobalt's criticality has impacted the behaviours of some states dependent on cobalt as they seek to capture value from or gain access to the cobalt supply.

4. Methodology and data

This chapter outlines the methodologies and data used in this research. The research employs a mixed-method design. Desk-based research and quantitative analysis are combined with qualitative research. For the most part, qualitative research builds directly on the results of desk-based and quantitative research. As such, the quantitative results are explained in more detail through the qualitative findings. The combination of quantitative and qualitative methods is intended to assess overlapping but also different facets of the cobalt sector, yielding an enriched, elaborated understanding of cobalt sector dynamics (Greene et al., 1989). The research sets out 'outcomes' before looking to understand the behaviours that have shaped those outcomes. Outcomes are explored in Part II and behaviours in Part III of the dissertation.

The term *quantitative research* is used to refer to a type of research that is explaining phenomena by collecting numerical data that are analysed using mathematically based methods (Creswell, 1994). The term *qualitative research* is used in its most basic sense to refer to empirical research where the data are not in the form of numbers (Punch, 1998) and which occurs in a natural setting enabling the researcher to develop a level of detail from high involvement in the actual experiences (Creswell, 1994).

In Part II, quantitative research is used to understand outcomes in the cobalt sector. Chapter 5 utilises secondary data on cobalt production and consumption. The chapter has used data available on cobalt supply and demand, based on a wide range of industry reports, company reports, trade journals, and government publications. Chapter 6, examines the International Trade Network (ITN) for cobalt units, to show the evolution of import-export relationships between all countries engaged in cobalt trade over time. This involves the examination of international trade flows using graph-theoretic structures where countries (vertices, or nodes) are linked by edges or links (representing the value/volume of a trade) to show import-export relationships between countries (see for example Bhattacharya et al., 2007; Benedictis & Tajoli, 2011; Abbate et al., 2012).

In Part III, to understand behaviours, the research applies a mixture of approaches. The cobalt sector is secretive and opaque. In many cases, information regarding things as diverse as ownership, capacity, production, processing techniques, trade, consumption, supply chain partnerships and even product is deemed commercially sensitive. While some information can be gathered from desk-based research and from published sources, such as the reports of publicly listed companies, much has to be gleaned through the development of contacts and relationships. This research is concerned with the behaviours of firm- and non-firm actors. It is certainly not possible to understand behaviours from publicly available information. In light of the nature of the cobalt sector and the focus of this research, a combination of case studies, questionnaire survey and semi-structured personal interviews were selected to explore the behaviours of firms and states.

A case study is a systematic enquiry into an event or a set of related events which aims to describe and explain the phenomenon of interest (Bromley, 1990). Put another way, a case study is an empirical inquiry about a contemporary phenomenon, set within its real-world context (Yin, 2009). A case study approach is particularly useful when the researcher is trying to uncover a relationship between a phenomenon and the context in which it is occurring (Gray, 2004). Case studies are used to provide context on firm- and state behaviours in the cobalt supply chain. Chapter 7 provides case studies on foreign direct investment and vertical integration in the cobalt sector. Chapter 8 presents case studies on reactions to cobalt's criticality from the DRC state and Chinese state.

A survey is a means of gathering information about the characteristics, actions, or opinions of a large group of people, referred to as a population (Pinsonneault and Kraemer, 1993). A survey has the advantage of gathering data for a representative group of actors to provide generalisable statements and data. Further, a questionnaire survey has the advantage of being a productive use of research time (Llieva et al. 2002) while reaching a wide geographic spread of respondents (Garton et al. 1999). A cobalt-sector survey was designed and circulated to cobalt sector actors to elicit generalisable statements and data about firm- and state responses to cobalt's criticality.

Interviews were used to build upon the findings of case studies and the cobalt-sector survey. Interviews have several advantages as a research method. They provide an opportunity to evaluate the validity of the respondent's answers by observing non-verbal indicators, which is particularly useful when discussing sensitive issues (Smith, 1975). They also ensure that the respondent is unable to receive assistance from others while formulating a response (Bailey 1987). Semi-structured interviews specifically allow depth to be achieved by providing the opportunity on the part of the interviewer to probe and expand the interviewee's responses and thus providing room for negotiation, discussion, and expansion of the interviewee's responses (Hitchcock and Hughes, 1989). In these interviews, the interviewer is in control of the process of obtaining information from the interviewee but is free to follow new leads as they arise (Bernard, 1988). Thus, while a structured interview is based on a fixed list of questions and allows little opportunity for digression, a semi-structured interview is open, allowing new ideas to be brought up during the interview as a result of what the interviewee says.

Figure 11 outlines the different methodological approaches used in this research and in which chapter they were used. These are explored in more detail throughout the rest of this chapter.

Figure 11: Overview of methodological approaches used in this dissertation

Part	Part II - Outcomes in the cobalt sector		Part III - Responses in the cobalt sector	
Summary	Part II examines outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time		Part III is concerned with identifying some of the causal mechanisms that have shaped the observed outcomes detailed in Part II. It explores how cobalt's criticality has shaped the behaviours of firms and states	
Chapter	C5. A GPN approach to examining how the cobalt supply chain is structured and organised	C6. An ITN approach to charting the reconfiguration of the cobalt supply chain	C7. Firm responses to cobalt's criticality	C8. State responses to cobalt's criticality
Research question	RQ1: How is the cobalt supply chain structured and coordinated?	RQ2: How has the spatial structure of the cobalt sector changed over time?	RQ3: How have firms responded to supply risk and economic importance?	RQ4: How have states responded to supply risk and economic importance?
Methodological approaches	A Global Production Network (GPN) approach	An International Trade Network (ITN) approach	Case studies, cobalt-sector survey, and semi-structured interviews	Case studies, cobalt-sector survey, and semi-structured interviews

Source: Author's construction

4.1 A Global Production Network (GPN) approach

The extractive industries have not been central to GPN analysis. Nonetheless, over the past decade there has been some extension of the approach into sectors such as energy (Bridge, 2008; Bridge and Bradshaw, 2017; Dicken, 2015; MacKinnon, 2013; Steen, and Underthun, 2011), base metals (Dicken, 2015; MacKinnon, 2013) bauxite (Knierzinger, 2018) and timber (Gibson and Warren, 2016). Chapter 5 applies a GPN approach to the cobalt sector in order to explore how the cobalt supply chain is structured and coordinated.

4.1.1 Data

Chapter 5 utilises secondary data on cobalt production and consumption. The chapter has used the most up-to-date data available on cobalt supply and demand, based on a wide range of industry reports, company reports, trade journals, and government publications. Detailed supply data are sourced from Roskill reports – see, for example, Roskill (2018) – on the cobalt market published since the 1970s, to which I was allowed access for the purposes of this doctoral study.

4.1.2 Data limitations

The utilisation of data from secondary sources has its limitations. It is not possible to ensure the accuracy of data from secondary sources, although every effort has been made to use reliable sources. The cobalt market is opaque and secretive. As such, access to reliable data is limited in some cases. Roskill reports, upon which much of the production data are based, note in their introductory pages how while it [Roskill] makes every reasonable effort to ensure the veracity of the information presented, it cannot expressly guarantee the accuracy and reliability of the estimates, forecasts and conclusions contained within its reports.

4.1.3 Methodology

In applying a GPN approach to the cobalt sector, this research followed the approach set out by Bridge (2008) who was the first to extend the GPN approach to the extractive resource sector through analysis of the oil sector. While no precise methodology was set out in Bridge (2008) the process was as follows:

1. Establish the structure of the commodity chain, outline key actors and relations that constitute the global production network.

The aim of this process is to lay the groundwork to show by comparison how a GPN approach that prioritises inter-firm relations and firm–state relations opens up a different way of thinking about extractive industries.

2. Expand the commodity chain into a global production network of inter-firm and firm–state relations that link nationalised companies, resource-holding states and publicly traded, transnational firms

These steps are carried out in chapters 5.1 and 5.2. An additional step is then undertaken, based on the approaches set out in Bridge and Bradshaw (2017) and Gibson and Warren (2016). This is to mobilise key concepts in GPN thinking to further explore the organisation and coordination of the cobalt GPN. Four concepts: value, power, embeddedness and materiality are thus explored in a cobalt-sector context in chapter 5.3.

4.2 An International Trade Network (ITN) approach

Chapter 6 sets out an International Trade Network (ITN) analysis of the cobalt supply chain. The chapter employs data on bilateral trade flows of cobalt units in quantity terms for all countries engaged in the international exchange of cobalt.

4.2.1 Data

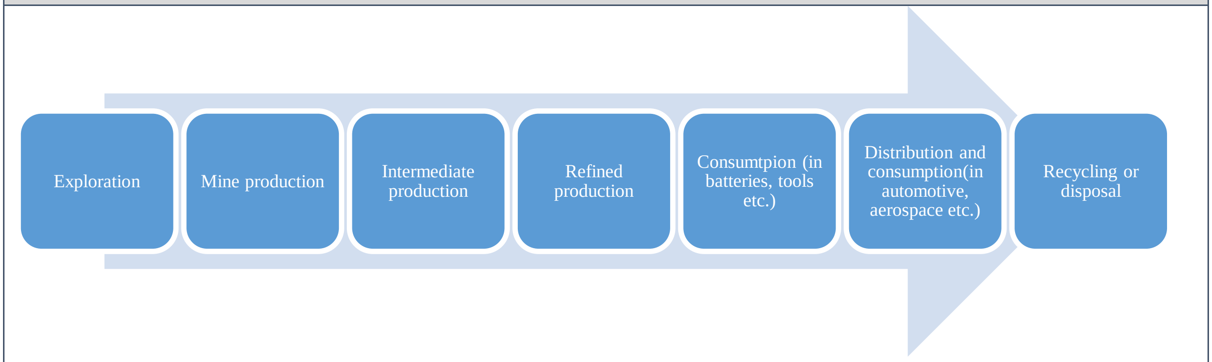
Data are sourced from Global Trade Tracker (GTT). GTT publishes authoritative, official trade data for 91 countries and facilitates analysis of trade flows for the countries whose data are not directly included. Its data are based on the Harmonized Commodity Description and Coding System and is reported in terms of value, quantity, and unit price, for both exports and imports.

The Harmonized Commodity Description and Coding System generally referred to as "Harmonized System" or "HS" is a multipurpose international product nomenclature developed by the World Customs Organization (WCO). It is comprised of roughly 5,000 commodity classes, each with a unique six-digit code. The system is used by more than 200 countries and economies as a basis for their Customs tariffs and for the collection of international trade statistics. According to the WCO, over 98% of the merchandise in international trade is classified in terms of the HS.

Using HS codes, and data reported by individual countries, it is possible to estimate cobalt trade flows. As shown below in Figure 12, the cobalt chain can be simplified into several key stages. Cobalt is traded internationally in the form of ores and concentrates, as well as in various intermediate and refined chemical and metal forms (shown as red in the figure below). While cobalt is also traded indirectly contained within final and consumer products (i.e. battery cathodes are traded internationally, as are lithium-ion batteries and laptops) this indirect trade is beyond the scope of this dissertation.

Figure 12: A simplified schematic of the cobalt supply chain

After exploration and the development of mine infrastructure, cobalt is mined, mostly as a by-product of copper and nickel. Ores are concentrated, and intermediate products are produced. These are further upgraded into refined products. These are consumed in the production of various products, the most significant being lithium-ion battery cathodes. Cobalt-containing products (such as lithium-ion batteries) are consumed in a wide number of end-use applications. Lithium-ion batteries are used mainly in consumer electronics and electric vehicles. These end-use products are either recycled or disposed of. At each stage cobalt products are traded domestically and internationally, often within the boundaries of firms.



Source: *Author's construction*

To take into account these stages, HS codes are grouped into four groups for the purposes of this dissertation: cobalt ores and concentrates, cobalt intermediates, refined cobalt chemicals and refined cobalt metal as shown in Table 7. In one case, an HS code is used for more than one group. These four groups form the basis of four different cobalt ITN studies in Chapter 6.

Table 7: Harmonised system codes for cobalt and corresponding ITN groups

HS Code	Description	ITN Group
260500	Cobalt ores and concentrates	Ores and concentrates
810520	Cobalt mattes and other intermediate products of cobalt metallurgy; cobalt, unwrought; cobalt powders	Cobalt intermediates
282200	Cobalt oxides and hydroxides; commercial cobalt oxides	Refined cobalt chemicals
282734	Cobalt chloride	
291523	Cobalt acetates	
810510	Cobalt, unwrought, matte & other intermediate products, waste, scrap & powders	Refined cobalt metal
810520	Cobalt mattes and other intermediate products of cobalt metallurgy; cobalt, unwrought; cobalt powders	
810590	Cobalt and articles thereof	

Source: WCO

4.2.2 limitations

While the coverage of GTT, and that of the underlying WCO data, is high, it is important to note that the data utilised is by no means perfect. GTT collects trade statistics from 60 official government offices and, as such, the accuracy of the data collected depends on the accuracy of government officials and firms operating in multiple jurisdictions. The following limitations should be considered, and the efforts made to address these limitations are noted below:

1. Countries do not necessarily report their trade statistics every year. This means that raw data may involve countries with no reported data for a specific year. As WCO data does not contain estimates for missing data, the trade of a country could be understated due to the unavailability of some country data.

Any obvious gaps in the data are addressed by an estimate and footnoted appropriately. The availability of data from importing and exporting countries means that in most cases, a trade value is available. For example, although the USA might not report exports of commodity x to the UK in any given year, the UK may report imports of commodity x from the USA.

2. Imports reported by a given country may not coincide with exports reported by its trading partner. Such differences are due to various factors including valuation, inclusions or exclusions of commodities, and the timing of reporting.

The annual trade volume between two countries, i and j, is described by four different quantities exp^{ij}*,* exp^{ji}*,* imp^{ij} *and* imp^{ji}*. Although recorded imports and exports between two trading counties should be identical, values that should theoretically appear the same, such as* exp^{ij} *and* imp^{ji}*, sometimes differ owing to incompleteness of the data caused by the timing and accuracy of reporting by individual countries. Where this is not the case, the directed trade flow between countries i and j are calculated as follows:*

$$exp^{ij} = \tfrac{1}{2}\, exp^{ij} + \tfrac{1}{2}\, imp^{ji}$$

3. When data are converted from a more recent to an older classification it is possible that the converted commodity codes contain more (or less) products than that implied by the official commodity heading. No adjustments are made for these cases.

No adjustment is made for these cases, although it is not thought that such reclassifications are relevant to cobalt units for the period under examination.

4. Almost all countries report a partner country for imports the country of origin, which is determined by the rules of origin established by each country. As such, the term ‘partner country’ in the case of imports does not necessarily imply any direct trading relationship.

The country of origin of a good (for imports) is determined by rules of origin established by each country and some countries so not have rules of origin at all (for more information see UN, 2015). No adjustments have been made for the purposes of this research.

5. Some countries may suppress commodity data if it would expose an exporter's or importer's trade flows directly. Hence to guarantee the local firms' confidentiality, the firms’ trade data could be suppressed.

Any suppression, or suspected suppression, of data are footnoted appropriately. As there are often several cobalt importers and exporters operating in each reporting country, suppression is not a major issue for the purposes of this research.

6. Cobalt units could be misreported. For example, government authorities could fail to report accurate data, or units could be accidentally classified under the incorrect HS code

While the data used is the best available, scrutiny of trade flows as classified under the HS suggests that, in some cases, materials are misreported or not classified correctly. By looking at the average unit value of imports/exports from any given country, estimating the likely cobalt content of a cobalt product, and comparing these values to the annual average for pure cobalt metal, it is possible to assess as to whether this has occurred on a case-by-case basis. In order to address this issue, the data has been 'cleaned', with footnotes identifying modifications to standard HS code trade flows as reported by GTT.

7. Trade data may include double-counting

Annualised trade data can contain instances of double counting. This is commonplace for countries that are home to entrepôt ports or cities. In the case of cobalt, a significant amount of material is imported by the Netherlands and subsequently re-exported. No adjustment is made for these cases, although likely cases of double counting are identified where necessary.

4.2.3 Methodology

Using the data detailed above, this chapter examines changes in the geographical scope of the cobalt chain through analysis of import and export flows of cobalt units over a ten-year period (T = 10 years, 2007 to 2017). The data are used to identify stylised facts about the cobalt ITN and explore key topological characteristics of the network, specifically network structure, density, centrality, and node and link strength.

4.2.3.1 Network structure

This data are used to build a time sequence of cobalt trade networks where countries are represented by N nodes and trade flows between two nodes are denoted by links L which represent trade volume (in tonnes) between two nodes in any given year. This process is undertaken for the four ITN commodity groups: cobalt ores and concentrates, cobalt intermediates, refined cobalt chemicals and refined cobalt metal, outlined above in Table 7. The results are tabularised, and import-export tables are produced for each calendar year between 2007 and 2017.

4.2.3.2 Network density

Network density refers to the number of potential connections in a network that are actual connections. A potential connection could exist between any two nodes existing in a network. An actual connection thus refers to two nodes existing in a network and being connected by a link. The density in a directed network is calculated as the ratio between existing links and the maximum number of possible links as follows:

D = no. of links / no. of nodes x (no. of nodes -1)

4.2.3.3 Degree centrality

Degree centrality refers to the most important links in a network. There are two separate measures of degree centrality, in-degree (Deg-in) and out-degree (Deg-out). In-degree is a count of the number of links directed to a node and out-degree is the number of links that the node directs to others. Thus, in-degree reflects import relations and out-degree reflects export relations on a network basis. These are calculated as follows:

Deg = no. of country links / no. of links[18]

4.2.3.4 Node and link strength

In a weighted network, the links between nodes have weights attached to them. In the case of this research, the weight assigned to links reflects tonnes of cobalt units in gross terms. For the purposes of this research, node and link strength are highly important, as many links within the trade network may represent only a small quantity of trade in tonnage terms.

Node in-strength (N-in) and out-strength (N-out) reflect the share of a country's total imports/exports to world trade. Both are defined as the sum of all trade weight associated with links of a node as follows:

N-in = total node imports (tonnes)/ total world imports (tonnes)

[18] Or degree = no. of country links / (no. of links -1) if a node is both an importer and exporter

Link strength is calculated to ascertain the number of links that represent more than 5% and 1% of total trade in any given year respectively:

Link strength = no. of links with volume (tonnes) > total world imports (tonnes)

4.3 Case studies

A case study involves a detailed examination of a subject. There are several advantages to a case study approach. First, case studies can result in a highly detailed examination of the subject in question. As they are anchored in real-life situations, case studies result in a rich and holistic account of a phenomenon, offering insights and meaning that expands its readers' experiences (Merriam, 2009). Second, case studies can create generalisable results and what is learned in a particular case can be transferred to similar situations (Erikson, 2986). Third, case studies can give insight into a phenomenon when data or other information on the said phenomenon does not exist.

Case studies also have disadvantages. Perhaps the most common critique of the approach is that they create results that cannot be generalised or isn't relevant to a wider population. Another common critique is that as case studies are typically assembled by one person, they are prone to reporting bias. This has been labelled an ethical issue as an unethical case writer could so select data on anything they wished to illustrate (Guba and Lincoln, 1981). Other critiques of case studies relate to their reliability, validity, and generalizability (Merriam, 2009).

Case studies are used in Part III of this dissertation in order to examine firm and state responses to cobalt criticality. In chapter 7.1.1, the research narrows its focus onto the DRC, charting the history of foreign direct investment in the Congolese cobalt sector. In chapter 7.2.1, a case study on the evolution of Huayou Cobalt, the world's largest producer of refined cobalt, is set out. Together, these case studies are used to present detailed examples of foreign direct investment and vertical integration. In chapters 8.1 and 8.2, case studies on the Congolese and Chinese states are set out in order to provide detailed evidence of these states' responses to cobalt's criticality.

4.4 A cobalt-sector survey

Survey research and surveys are used frequently in economic geography. There is an important distinction between survey research and surveys (Pinsonneault and Kraemer, 1993). Glasgow (2005) neatly summarises Kraemer (1991) who outlined three core characteristics of survey research. First, survey research is used to quantitatively describe specific aspects of a given population, involving examination of the relationships among variables. Second, the data required for survey research are collected from people and are, therefore, subjective. Finally, survey research uses a selected portion of the population from which the findings can later be generalised back to the population (Glasgow, 2005). In contrast, a survey is simply a data collection tool for carrying out survey research (Glasgow, 2005). A survey is a means of gathering information about the characteristics, actions, or opinions of a large group of people, referred to as a population (Pinsonneault and Kraemer, 1993).

Surveys have a number of disadvantages. Most of these relate to the subjective nature of responses. First, as Salant & Dillman (1994) note, surveys only provide estimates for the true population, not exact measurements. Second, survey responses are prone to bias, either in the lack of response from intended participants, or in the nature and accuracy of the responses that are received (Bell, 1996; Glasgow, 2005). Third, other sources of error are possible, including intentional misreporting of behaviours by respondents to confound survey results, or to hide inappropriate behaviour (Glasgow, 2005). Fourth, it has been noted that respondents may have difficulty assessing their own behaviour or have poor recall of the circumstances surrounding their behaviour (Glasgow, 2005). As such, it has been argued that surveys are not suitable where an understanding of the historical context of a phenomenon is required (Pinsonneault and Kraemer, 1993).

Nonetheless, surveys have a number of advantages. First, they are useful for both generating information, as well as assembling data about the population of respondents (McIntyre, 1999). Second, they serve as a way of gathering data about attitudes, behaviours or perceptions that are otherwise difficult to quantify. Third, they are, compared to interviews and other research techniques, not too labour intensive and thus serve as an efficient way of gathering insight (Llieva et al. 2002). Fourth, surveys have the advantage of being able to reach a wide geographic spread of respondents (Garton et al. 1999). In light of these benefits, a survey has been chosen as part of this research as it has the advantage of gathering data for a representative group of cobalt sectors actors to provide generalisable statements and data about firm and state responses to cobalt's criticality.

4.4.1 Cobalt-sector survey design

Survey design was initiated in March 2018. A written (electronic) survey was selected as this could be developed and circulated most easily to geographically dispersed respondents. Further, it has been argued that written surveys are best suited to prompting confidential information and elicit minimal interviewer and respondent measurement errors due to the absence of direct contact (Glasgow, 2005).

Due cause and consideration were given to the structure and wording of the survey. Effort was made to ensure that that questions and response options were clear to the respondent and that the wording of questions was not ambiguous and thus susceptible to misinterpretation (Fowler and Floyd, 1995). This was particularly important as many respondents completed the English language survey in their non-native language. The survey was also purposefully short in length, as too long a survey could discourage respondents and potentially impact results (McIntyre, 1999). Every effort was made to avoid the use of jargon, although some necessary technical terms (such as critical materials) were defined at the start of the survey in a short glossary.

As is widely considered appropriate, rating scales were balanced to provide an equal number of positive and negative response options (Salant and Dillman, 2004). A Likert scale approach was employed. The Likert scale is a special type of the more general class of summated rating scales constructed from multiple ordered-category rating items (Lavrakas, 2008). Its distinguishing characteristics are summarised by Lavrakas (2008) as follows. First, each item uses a set of symmetrically balanced bipolar response categories indicating varying levels of agreement or disagreement with a specific stimulus statement expressing an attitude or opinion. Second, the response category points for each item are individually labelled. Third, the descriptive text of these labels is chosen so that gradations between each pair of consecutive points seem similar.

The survey script is shown in full in the Appendix, although a sample of three questions is set out below.

Please indicate whether you agree with the following statements:

		Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
B1	Concerns over "supply risk" have motivated firms to undertake foreign direct investment in cobalt assets	☐	☐	☐	☐	☐
B2	"Supply risk" is the *main* reason for firms having undertaken foreign direct investment in cobalt assets	☐	☐	☐	☐	☐
B3	"Economic importance" and expectations of future demand growth are *major* reasons for firms having undertaken foreign direct investment in cobalt assets	☐	☐	☐	☐	☐

Questions were grouped into five main sections, centred around research questions and hypotheses. In all cases, respondents were asked to assess their own views in light of a presented statement. Section

A, “General Questions” consisted of three introductory questions related to the central consideration of this research – whether or not by responding and reacting to cobalt’s criticality, firms and states have shaped the geographies and structure of the cobalt supply chain.

Sections B and C were designed to gather data to help answer RQ3: How have firms responded to supply risk and economic importance? Section B, “Foreign Direct Investment in the Cobalt Sector”, was comprised of seven questions related to the hypothesis that firms have engaged in foreign direct investment (FDI) and resource-seeking. Section C, “Integration in the cobalt supply chain”, was comprised of seven questions related to the hypothesis that firms have vertically integrated both forwards and backwards.

Sections D and E were designed to offer insight to help answer RQ4: How have states responded to supply risk and economic importance? Section D, “The Democratic Republic of the Congo”, consisted of nine questions and Section E, “China”, was made up of seven questions. These were included to test two key hypotheses. The first was that resource-holding states will have undertaken resource nationalist approaches in order to capture value from the cobalt sector. The second was that resource-seeking states have created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value from the cobalt sector.

Section F was comprised of only one question and asked respondents whether they would be happy to be contacted for a follow-up interview.

An initial pilot survey was developed in April 2018 and tested with a small number of colleagues at Roskill in London. This enabled me to test the survey, and survey procedures, before circulating it more widely. Further to feedback, consultation with my supervisors, and some revisions to wording and structure, the survey was finalised in May 2018.

4.4.2 Cobalt-sector survey sample and distribution: representing the cobalt universe

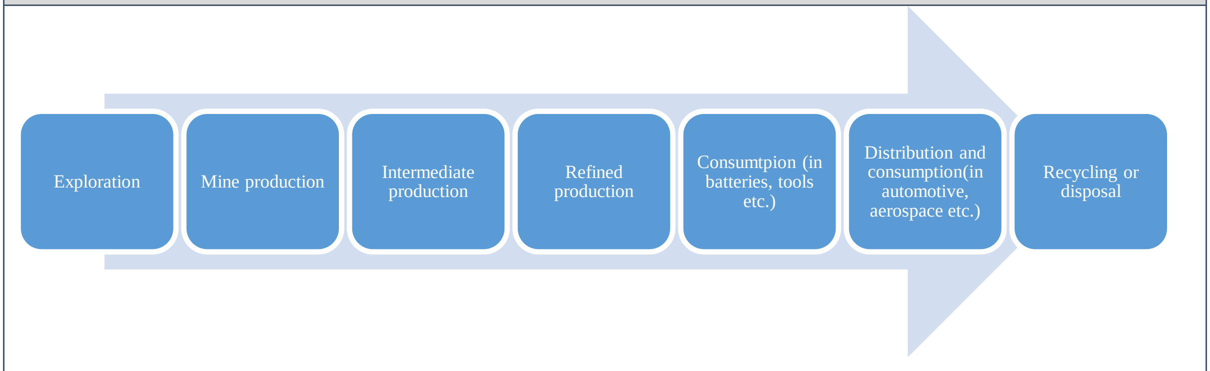
Sample selection depends on population size, its homogeneity, the sample media and its cost of use, and the degree of precision required (Glasgow, 2005; Salant & Dillman, 1994). Importantly there should be no biased selection of respondents. Crucially, a sample should be large enough and representative enough to yield meaningful results.

Clearly, the focus of this research is on the cobalt sector. However, this is not an objectively quantifiable or qualifiable sector. For example, while some cobalt producers could be said to work for "cobalt firms" most cobalt producers also produce, for example, copper or nickel. By way of another example, major consumers of cobalt, and therefore integral parts of the cobalt supply chain, are firms more generally considered to be part of the technology and electronics sectors (such as Apple or Panasonic) or aerospace and automotive sectors (such as Rolls Royce and Volkswagen).[19]

In light of this ambiguity of sectoral classification, the linear conceptualisation of the cobalt supply chain can be mobilised to assess a suitable sample representation. This (Figure 13) splits the cobalt supply chain into several distinct stages.

Figure 13: A simplified schematic of the cobalt supply chain

. After exploration and the development of mine infrastructure, cobalt is mined, mostly as a by-product of copper and nickel. Ores are concentrated, and intermediate products are produced. These are further upgraded into refined products. These are consumed in the production of various products, the most significant being lithium-ion battery cathodes. Cobalt-containing products (such as lithium-ion batteries) are consumed in a wide number of end-use applications. Lithium-ion batteries are used mainly in consumer electronics and electric vehicles. These end-use products are either recycled or disposed of. At each stage cobalt products are traded domestically and internationally, often within the boundaries of firms.



Source: Author's construction

A suitable representative sample population for the cobalt sector survey should include responses from people engaged in the various stages of the supply chain. However, the groupings set out in Figure 13 need some further revision for several reasons. First, because producers typically undertake more than one stage of cobalt production (mine, intermediate, refined), some consideration of this fact is required. As such, the groupings below split producers into mine/intermediate producers, refined producers, and

[19] Based on the analysis set out in Part II of this research, this research identified 137 firms that produce cobalt in some form.

integrated producers, thus capturing different types of producing firm. Second, because consumption and end-use of cobalt are often undertaken by the same firms, these two stages of the supply chain (as set out in Figure 13) are grouped together as "end-users" below. Third, because the opinions of a variety of other actors are also worthy of consideration (analysts, journalists, traders, financiers etc.) several other groupings have been included. Table 8 shows 12 groupings for desired respondents.

Table 8: Sample groups for cobalt-sector survey

Mine/intermediate producer	Journalist
Refined producer	Analyst
Integrated producer	Trader
Recycler	Other
Project	Finance
End-user	Anonymous

Source: Author's construction

In order to publicise my research and introduce the survey to cobalt-sector actors, I gave an overview of my PhD work following my presentation of a paper (entitled: Supply-side changes in the cobalt market) at the Cobalt Institute's Annual Conference in Las Vegas, USA, 23-24th May 2018. Paper versions of the survey were left in conference areas for anonymous completion and subsequently collected. Further to this, an introductory letter was drafted, and the survey was sent by email to all delegates (228 not including myself) at the conference on 31st May 2018. It was clearly stated that individual responses would be anonymous and that all data would be held in confidence. This was particularly important, as it allowed respondents to answer questions without concern that responses would be made public. It also helped to address the concern that respondents would feel uncomfortable providing answers if these would be directly attributed to their employers' organisations.

Additionally, the survey was sent out to Roskill's cobalt marketing distribution list on 12th July 2018. This list consists of 238 email address of people likely to have an interest in the cobalt sector. Thus, in total, the survey was sent to a total of 466 potential cobalt-sector respondents.

4.4.3 Cobalt-sector survey responses

From the potential 466 cobalt-sector respondents a total of 97 completed the cobalt-sector survey (21%). As noted above, an advantage to surveys is the fact that as well as assembling data about the subject in question, they enable the collection of data about the population of respondents. Table 15 shows the profile of cobalt sector-survey respondents.

Table 9: Profile of cobalt-sector survey respondents	
Grouping	Number of respondents
Mine/intermediate producer	2
Refined producer	10
Integrated producer	6
Recycler	2
Project	14
End-user	10
Journalist	2
Analyst	10
Trader	8
Other	8
Finance	3
Anonymous	22
Total	**97**

While all responses are anonymous, below some information is presented about respondents in each category for context:

Mine/intermediate producers – mine cobalt (typically as a by-product of copper or nickel). The (2) respondents were both operations in the DRC that mined cobalt and produced cobalt hydroxide for export (mostly to China). One operation was 100% privately owned by a non-Congolese firm, the other was a joint venture between a foreign firm and state-owned enterprise, Gécamines.

Refined producers – produce cobalt metal or chemical but have no upstream (mine and intermediate) production assets. Of the (11) respondents, nine were from Chinese firms with one from Europe and one from North America.

Integrated producers – undertake mine, intermediate and refined production of cobalt. The (7) respondents were from six firms with operations spread across Africa and North America.

Recyclers – process battery scrap and other materials to produce new materials. Only (1) recycler was known to respond to the survey and is based in Europe. Note that some Chinese refined producers also undertake cobalt recycling.

Projects – are developing cobalt mines. In total (14) responded to the cobalt-sector survey. Five were based in North America, four in Oceania and three in Africa.

End-users – consume refined cobalt in the production of their products (e.g. a lithium-ion battery producer or consume cobalt-bearing products in the production of their produces (e.g. an electric vehicle producer). The (10) respondents included technology firms, car producers, specialist chemicals producers, and alloy manufactures and were located in Europe, North America, Asia and Africa.

Journalists – are increasingly writing about cobalt and other critical materials. The (1) respondent to the cobalt-sector survey is Commodities Editor for a leading broadsheet newspaper.

Analysts – refers to those who work for government organisations, pricing and news publications, or independent consultancies. The (10) respondents were from the UK and China and all had specialist knowledge of the cobalt market.

Traders – buy and sell cobalt in its various forms, typically as a metal, but also as an unrefined material or chemical. In total (8) traders responded to the cobalt-sector survey. Seven were based in Europe and one in China.

Finance – refers to investors in physical cobalt, hedge funds, investors in cobalt equities and those involved in cobalt project finance. Of the (3) respondents, two were from Europe and one from North America.

Others – included those in institutional bodies relevant to the cobalt sector, actors involved in related commodities (such as lithium) but not cobalt specifically, specialist lawyers and advisory firms, and assayers. Respondents were located in Europe, North America, Asia, Africa and Oceania.

Anonymous – as noted above paper versions of the survey were left in conference areas for anonymous completion and subsequently collected.

Excluding anonymous responses, the largest group of respondents were cobalt producers (24%). Of these, 13% worked for refined producers, 8% fully-integrated producers and 3% mine-intermediate producers. The second-largest group of respondents were those who worked for cobalt sector projects (19%). Thus, a total of 43% of survey responses were from producers or potential producers of cobalt. End-users accounted for 13% of respondents and traders for 12%, meaning that the direct recipients of cobalt produced by the aforementioned producers accounted for 25% of survey responses. As such, there was a suitable distribution of respondents across the groupings set out above.

Table 10 shows the same data on a regional basis. In total 44% of respondents were European, 19% Asian, 17% North American and 12% African. This again represents a suitable geographic distribution of respondents albeit with a notable bias towards European respondents.

Table 10: Geographical profile of cobalt-sector survey respondents	
Grouping	Number of respondents
Africa	9
Asia	14
Europe	33
North America	13
South America	1
Oceania	5
Anonymous	22
Total	**97**

4.4.4 Cobalt-sector survey statistical testing

In order to test the significance of results, some basic statistical tests were performed on survey data. A one-sample t-test was used to compare the mean to a specified theoretical mean (μ). This was taken as the average of the potential Likert scale scores (5,4,3,2,1 = 3). Given the number of cobalt-sector survey responses, n=97. In the equation below, m = mean and s = standard deviation.

$$t = m - \mu / s \sqrt{n}$$

The P-value, or calculated probability, was then calculated using a 0.1% significance level (one-tailed hypothesis).

4.5 Semi-structured interviews with cobalt-sector actors

Unlike other forms of empirical research, interviews, or what Gordon Clark labelled close dialogues, rely upon the intimacy or closeness of researchers to industry respondents, a level of personal commitment quite at odds with the conventional notions of scientific disassociation and objectivity

(Clark, 1998). An interview can be defined as a conversation with the purpose of gathering a respondent's description and interpretation of described phenomena (Kvale, 1996).

Interviews have a number of advantages over other research methods. They provide an opportunity to evaluate the validity of the respondent's answers by observing non-verbal indicators, which is particularly useful when discussing sensitive issues (Smith, 1975). They also ensure that the respondent is unable to receive assistance from others while formulating a response (Bailey, 1987).

Interviews can take many forms, including structured interviews, organised around predetermined questions, and unstructured interviews, which are undertaken with no set structure or format in place. A third type is the semi-structured interview, which can be considered a more flexible version of the structured interview, or indeed, a more guided version of the unstructured interview.

Semi-structured interviews allow depth to be achieved by providing the opportunity on the part of the interviewer to probe and expand the interviewee's responses and thus providing room for negotiation, discussion, and expansion of the interviewee's responses (Hitchcock and Hughes, 1989). In these interviews, the interviewer is in control of the process of obtaining information from the interviewee but is free to follow new leads as they arise (Bernard, 1988). Thus, while a structured interview is based on a fixed list of questions and allows little opportunity for digression, a semi-structured interview is open, allowing new ideas to be brought up during the interview as a result of what the interviewee says.

To build upon the findings of the cobalt sector survey, semi-structured interviews were selected for the purposes of this research. While the survey, necessarily and intentionally, gathers data and opinions only on specified subjects, semi-structured interviews allowed for new ideas on the nature of the cobalt market to emerge as they facilitated the broadening of discussion points based on key areas of knowledge held by each interviewee (Denscombe, 2007). Further, they allowed for respondents to provide information on the cobalt sector that might not have been gleaned had interview topics been confined solely to those chosen by the interviewer, or has this research limited itself only to the findings of the cobalt sector survey. The use of semi-structured interviews enabled me to capture original responses which can be used to construct insightful and original research narratives.

A good deal of the literature in social science argues that face-to-face interviews are preferable to telephone interviews in qualitative research (Gillam, 2005; Legard et al. 2003). The argument goes that face-to-face meetings have the advantage of being more natural and conducive to the parties involved developing *rapport*, with the format leaving less room for breakdowns of communication or misinterpretation (Burnard, 1994; Shuy, 2003). Another key thread of advocacy for face-to-face interviews relates to body language. Gillam (2005) notes that though losing non-verbal elements of communication, telephone calls strip out a layer of meaning. Opdenakker (2006) suggests such elements, or social cues, could indeed be important information for the interviewer. Nonetheless, there are also many advocates of telephone interviews with proponents highlighting that they save time and money and enable the interviewer to reach a wider geographic pool of respondents (Sturges and Hanrahan, 2004).

Section F of the survey was comprised of only one question and asked respondents whether they would be happy to be contacted for a follow-up interview. Those respondents that answered positively to this question were contacted for face-to-face interviews. In total, 18 interviews were carried out between 22nd May 2018 and 31st December 2018 on this basis. Several of these were with subjects that I had developed a professional relationship with over time. Over the course of this part-time PhD research, and throughout my employment at Roskill, I have worked to develop close relationships with a wide number of cobalt-sector actors. Some I have known for over seven years. Through discussion of the cobalt sector with these contacts, this research is able to draw upon unique insights from industry actors shared as a result of, in many cases, long-standing personal and professional relationships.

Further, from 27th January 2019 to 7th February 2019, I travelled the DRC, Zambia and South Africa as part of a cobalt-focussed research trip for my employer. This enabled me to conduct an additional 11 face-to-face interviews with geologists, traders, depot workers, and those working at mines in Central Africa.

An additional six interviews were held at the Cobalt Institute Conference in Hong Kong, 14th-15th May 2019. This gave an opportunity to follow up on key themes explored during previous interviews over a different time period. Thus, in total 35 interviews were conducted as part of this study.

Table 15 shows the profile of interview respondents. The largest group of respondents were integrated producers (21%). A further 14% of respondents were mine intermediate producers, refined producers, or worked for cobalt projects. As such, cobalt producers and potential producers accounted for 52% of interview respondents. No interviews were conducted with recyclers.

Table 11: Profile of interview respondents	
Grouping	Number of respondents
Mine/intermediate producer	4
Refined producer	1
Integrated producer	6
Recycler	0
Project	4
End-user	4
Journalist	2
Analyst	3
Trader	4
Other	6
Finance	1
Total	**35**

Table 10 shows the same data on a regional basis. This demonstrates some regional bias with regard to interview respondents. In total, 55% were European and 41% were African. A total of 14% were North American and 10% Asian. There were no respondents from South America or Oceania.

Table 12: Geographical profile of interview respondents	
Grouping	Number of respondents
Africa	12
Asia	3
Europe	16
North America	4
South America	0
Oceania	0
Total	**35**

As was the case with the cobalt-sector survey, it was made clear to interview subjects that individual responses would be anonymous, and that all data would be held in confidence. As such, in the analysis in Part III, respondents are referred to by a number (R1-R35) as well as generalised terms such as "a cobalt trader" or "a European automotive producer".

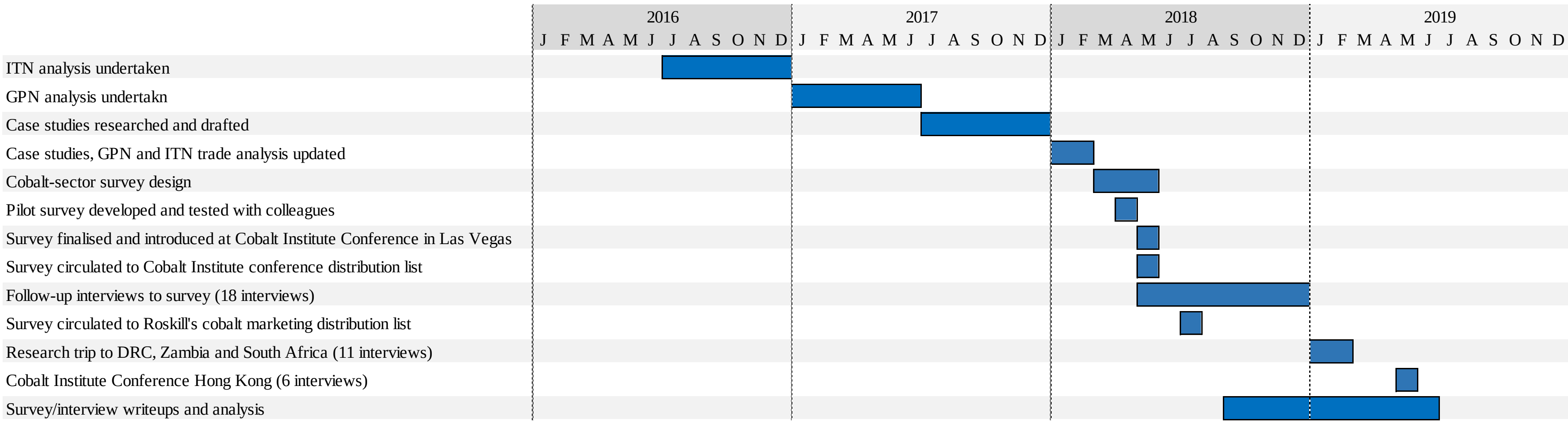
4.6 Overview of work stages

Figure 14 shows how the key stages of work were undertaken. The bulk of the desk-based and empirical research was undertaken over a three-year period between July 2016 and July 2019.

In 2016 and 2017, efforts were concentrated on desk-based research. During this time, the bulk of the GPN analysis that would form chapter 5, and the ITN research and analysis that would form chapter 6, was undertaken. Furthermore, the case studies on FDI in the DRC cobalt sector (chapter 7.1.1), vertical integration in the cobalt sector (chapter 7.2.1), China (chapter 8.1) and the DRC (chapter 8.2) were constructed. These parts of the research were further refined and updated in early 2018. These chapters represented the majority of the desk-based and quantitative research used in the dissertation.

As noted above, for the most part, qualitative research built directly on the results of desk-based and quantitative research. The bulk of the qualitative research was undertaken in 2018 and 2019 beginning with a survey. Cobalt sector survey design began in March 2018 and after pilot testing, the survey was formally launched in May 2018 at a Las Vegas cobalt conference. Where possible, it was hoped that interviews could be used to build upon the findings of the survey (respondents to the survey were asked if they would agree to a follow-up interview). Pleasingly, 18 follow-up interviews were undertaken over the May to December 2018 period. As shown in Figure 14, additional interviews took place in early 2019, during a research trip to Central Africa and at Hong Kong cobalt conference. Survey and interview analysis was undertaken over a 10-month period in 2018 and 2019.

Figure 14: Gantt chart overview of key research stages



Source: Author's construction

4.7 Ethics and risks

Every effort has been made to ensure that this research conforms to the University of Cambridge Policy on the Ethics of Research. The use of a survey and semi-structured interviews prompts certain ethical considerations. Diener and Crandall (1978) set out four key ethical areas for consideration in research: whether there is harm to participants, whether there is a lack of informed consent, whether there is an invasion of privacy, and whether deception is involved.

4.7.1 Harm to participants

It is generally held that it is the responsibility of the researcher to assess the possibility of harm to respondents and to minimise any potential risks (Bryman and Bell, 2007). It has also been argued that there is a need to consider the interests of non-participants, especially when the research has practical implications in determining social policies (Gorard, 2002). Maintaining the confidentiality and anonymity of respondents is central to the mitigation of harm. This is because there have been documented instances of reputational damage to participants who were identified as a result of poor anonymisation on the part of the researcher (Parker, 2000).

Thus, it was important to protect the anonymity of respondents to the cobalt-sector survey and, in particular, semi-structured interviews. Failure to do so posed a risk of harm. Respondents gave personal and, at times, politically and commercially sensitive responses to the questions they were asked, which may have been at odds with the official stance of their firm or organisation. Further, respondents gave open views on the governments of China and the DRC, countries to which a cobalt-sector participant is likely to travel to. As such, it was imperative that such views and responses were not publicly attributable to the respondents, else they may be at risk of being found in breach of contractual obligations.

It was clearly stated in the opening statement of the cobalt-sector survey and at the beginning and end of interviews that individual responses were to be anonymous, and all data would be held in confidence. In the dissertation, respondents are referred to only by a code, for example, "R1". While short descriptions have also been included to aid the flow of the narrative, these are kept generic so that respondents cannot be identified. For example, respondents may be referred to as "a cobalt trader" or as a "representative of a North American cobalt project". Every effort has been made to ensure that no identities can be inferred from such descriptions. No company names were used, and geographic descriptions were only used if there was no heightened risk of identification. This is important in a sector like cobalt, as the cobalt universe (in terms of sample size) is relatively small compared to other sectors and thus the possibility that firms or individual employees could be identified is significant.

4.7.2 Lack of informed consent

The issue of informed consent relates to ensuring that research participants understand the scope, nature, purpose and reach of the research so that they have all the facts when deciding whether to be involved. Studies have, in some cases purposefully, preferred an 'undercover' approach and thus not informed participants of their role in, or the realities of, the research. A well-cited example is that of Dalton (1959) who observed management practices in a chemical plant in the US Midwest and purposefully kept the nature of his research from participants in order to gather results that were not changed by the act of observation.

The issue of informed consent is closely related to the issue of harm to participants. As Erikson (1967) argues, if participants are harmed as a result of research and have not given informed consent, the researcher is more culpable than would be the case is the respondent had given consent and knew the risks involved.

To ensure informed consent, both the cobalt-sector survey and semi-structured interviews were introduced with an overview of the research and its core aims. It was clearly stated that the purpose of the questionnaire and interviews was to gather the views of market participants on how cobalt's "criticality" has affected the behaviours of firms and states. As noted above, it was made clear that individual responses were to be anonymous, and all data would be held in confidence.
Invasion of privacy

It is important that the privacy and values of respondents are protected during the course of the research process. While the granting of informed consent to an extent implies the surrender of certain rights to privacy, it does not abrogate the right to privacy entirely (Bryman and Bell, 2007).

Care was taken to ensure that this research conformed to the requirements of The Data Protection Act, the UK's implementation of the General Data Protection Regulation (GDPR). This imposes responsibilities on students accessing and recording personal data and mandates the storage and use of data in a secure manner, ensuring that data are handled in line with what individuals have been told, and making sure that individuals' data are accurate and retained for a suitable period.

Every effort was made to protect privacy through appropriate data storage. All interview write-ups and survey responses were stored on password-protected computers in password-protected files. With regard to interview subject matter and privacy, every effort was made to ensure that questions did not probe into areas that could be deemed as sensitive. For example, respondents working for cobalt sector were not asked to comment on matters that may have been construed as commercially sensitive.

4.7.3 Deception

Deception, as it relates to research ethics, typically involves the withholding of information from respondents. Athanassoulis and Wilson (2009) make the distinction between normative and non-normative accounts: normative accounts of deception make the ethical question of whether a particular case of misleading is justifiable integral to the question whether it counts as a case of deception, whilst non-normative accounts do not. Typically, researchers that choose to deceive respondents as to the true scope or purpose of the research in question so that results are not negatively impacted by observation. Every effort was made not to deceive respondents as to the purpose and scope of this research.

4.7.4 Risks

Before conducting the interviews, due care and attention were paid to assessing potential risks and implementing sufficient control measures to help mitigate them. As set out in the Research Ethics Guidebook (ESRC, 2019), interviews can present the risk of physical threat or abuse; the risk of psychological trauma as a result of actual or threatened violence or the nature of what is disclosed during the interaction; the risk of being in a comprising situation in which there might be accusations of improper behaviour; the increased exposure to risks of everyday life and social interaction such as road accidents and infectious illness; and the risk of causing psychological or physical harm to others.

The most pertinent of these given the nature of this research was increased exposure to risks of everyday life and social interaction. Primary research for this dissertation was conducted in a variety of locations, including at Cobalt conferences in Las Vegas and Hong Kong, and at cobalt production sites in the DRC and Zambia. All trips were carefully planned from a risk management and safety perspective.

4.7.5 Summary: a mixed-methods approach to understanding the cobalt supply chain

Focussing on the 2007 to 2017 period, the aim of this research is to determine how the cobalt supply chain is structured and organised, how its structure and organisation have evolved temporally and geographically, how firms and states have responded to cobalt's criticality (supply risk and demand growth), and how these responses have resulted in spatial and structural outcomes. The research aims to identify the behaviours that have shaped various outcomes in the cobalt supply chain, as well as the outcomes themselves, and does so by asking and answering four key research questions. No single methodological approach can be applied to meet these research aims or answer these research questions. Thus, the research, necessarily, combines several approaches.

The chapters which explore outcomes (in Part II), in combination, set out a detailed description of how the cobalt supply chain is structured and how it has changed over time. They make use of a range of firm- and state-level data and importantly utilise recent approaches to supply chain and trade analysis, making sure that the research utilises some of the more novel tools of contemporary economic geography. The chapters which explore behaviours (in Part III) unearth original comments and opinions derived from the experiences of actors directly involved in the supply chain. In combination, it is hoped that these approaches yield a deeper understanding of the cobalt sector and its underlying formulative dynamics.

Part II

Part II of this dissertation is concerned with observed outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time, focussing on the 2007 to 2017 period. This is achieved over the course of three chapters:

Chapter 5 extends the Global Production Network (GPN) approach to the cobalt sector and in doing so explores the structure and organisation of the cobalt supply chain. This represents the first known application of a GPN approach to a critical material market. The chapter first introduces the cobalt sector through a linear chain conceptualisation and outlines key stages of production and consumption, as well as the main actors involved. Thereafter, a GPN for cobalt is presented following the approach set out by Bridge (2008) who first extended the GPN approach to the extractive resource sector using the oil industry as a case study. Subsequently, the chapter employs tools from the GPN analytical toolkit to further examine the cobalt supply chain's formation and structure. The chapter addresses RQ1: How is the cobalt supply chain structured and coordinated?

Chapter 6 addresses RQ2: How has the spatial structure of the cobalt sector changed over time? The chapter presents the first known International Trade Network (ITN) analysis of a critical material in order to uncover stylised facts about changes to the cobalt supply chain over time. This represents a novel approach, as such analysis is usually at the aggregate or commodity-class level. Several statistical approaches, typical of ITN studies, are applied to examine changes in the over the period of analysis.

In combination, Chapters 5 and 6 explore structural and spatial "outcomes" in the cobalt sector. They outline how the supply chain is structured, organised and coordinated and how these factors have changed over time. The chapters in Part III have the goal of developing a better understanding of the causal mechanisms that have shaped these observed outcomes.

Figure 15 provides an overview of the structure of the thesis. The relevant chapters and research questions for Part II are highlighted in red.

Figure 15: Dissertation structure

Part	Part I - Research background				Part II - Outcomes in the cobalt sector		Part III - Responses in the cobalt sector		Part IV - Discussions and conclusions
Summary	Part I introduces the reader to the debates surrounding resource scarcity and critical materials and the cobalt sector. It then reviews the literature relevant to the research				Part II examines outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time		Part III is concerned with identifying some of the causal mechanisms that have shaped the observed outcomes detailed in Part II. It explores how cobalt's criticality has shaped the behaviours of firms and states		Part IV contains the research's conclusions
Chapter	C1. Introduction	C2. Resource scarcity, critical materials and the case of cobalt	C3. Theoretical debates on the nature and organisation of global supply chains	C4. Methodology	C5. A GPN approach to examining how the cobalt supply chain is structured and organised	C6. An ITN approach to charting the reconfiguration of the cobalt supply chain	C7. Firm responses to cobalt's criticality	C8. State responses to cobalt's criticality	C9. Conclusions and discussion
Summary	Introduces the research and outlines its background aims, key questions and structure	Introduces key literature on resource scarcity and critical materials before selecting a case study raw material (cobalt)	Introduces theories of international trade, theories of the firm and theories of global chains and networks relevant to the research	Discusses the use of GPN and ITN approaches for Part II and the use of case studies, a survey and semi-structured interviews for Part III	Uses a Global Production Network approach to show how the cobalt supply chain is structured and coordinated	Uses an International Trade Network approach to show how the geographies of the cobalt chain have evolved over time	Focussing on the upstream part of the sector in the DRC, the chapter looks at how firms have responded to cobalt's criticality exploring FDI and integration in particular	Focussing on the cobalt sector's major resource-holding state (the DRC) and resource-seeking state (China) this chapter explores how states have responded to cobalt's criticality	This chapter outlines key research conclusions, discusses the implications of the research findings, and outlines areas for additional study
Research questions addressed					RQ1: How is the cobalt supply chain structured and coordinated?	RQ2: How has the spatial structure of the cobalt sector changed over time?	RQ3: How have firms responded to supply risk and economic importance?	RQ4: How have states responded to supply risk and economic importance?	

Note: Red lines denote the current part

5. A GPN approach to examining how the cobalt supply chain is structured and organised

This chapter explores the structure and organisation of the cobalt supply chain. It does so by extending the global production network (GPN) approach to the cobalt sector. This represents a novel approach, as the extractive industries have not been central to GPN analysis and there has been no focus on critical materials, despite some GPN research into energy (Bridge, 2008; Bridge and Bradshaw, 2017; Dicken, 2015; MacKinnon, 2013; Steen, and Underthun, 2011), base metals (Dicken, 2015; MacKinnon, 2013) bauxite (Knierzinger, 2018) and timber (Gibson and Warren, 2016).

Chapter 5.1 provides the necessary first step of providing some background information on the cobalt sector. It explains what cobalt is, how and why it is produced and consumed, and introduces the network of firms and non-firm actors through which cobalt production, distribution, and consumption are coordinated.

Chapter 5.2 sets out a global production network for cobalt. It does so by following the approach set out by Bridge (2008) who first extended the GPN approach to the extractive (non-renewable) resource sector, using the oil industry as an illustrative case.

Chapter 5.3 mobilises certain key tools used in GPN thinking that are used to explore the configuration and coordination of networks by firm and extra-firm actors: value, power, embeddedness, materiality and strategic coupling. The chapter uses these variables to examine the structure and organisation of the cobalt supply chain.

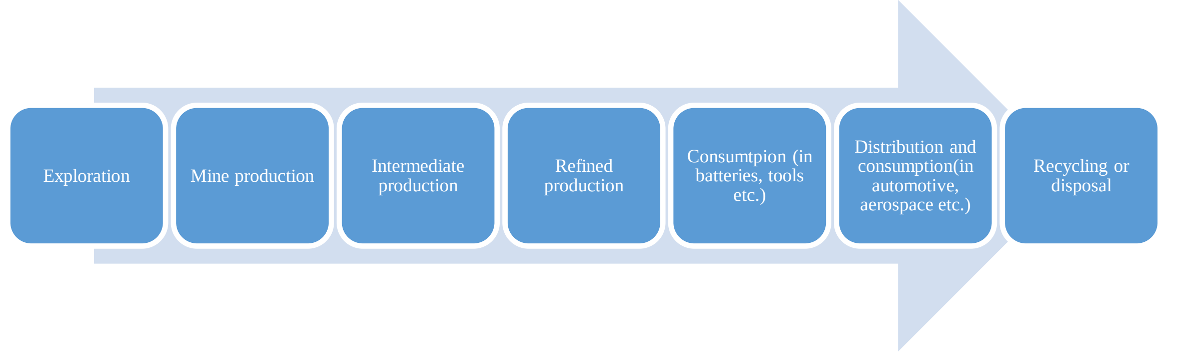
Chapter 5.4 considers the findings of the preceding analysis in light of the research questions and hypotheses set out in Part I of this dissertation. The chapter addresses RQ1: How is the cobalt supply chain structured and coordinated?

5.1 A linear conceptualisation of the cobalt supply chain

Cobalt is a widely utilised metal consumed in lithium-ion batteries, superalloys, tools, magnets and a variety of other applications. The cobalt supply chain is highly complex and global in reach. Cobalt is mined mostly in Central Africa, but also on five other continents, before being upgraded and traded internationally to operations that produce refined cobalt products, most of which are in Asia. Cobalt producers include state-owned-enterprises, transnational corporations (TNCs), joint-venture companies and smaller, private and public firms. Consumers range from small engineering firms to large TNCs such as Panasonic and Apple. Figure 16 shows a simplified, linear schematic of the cobalt supply chain. The various stages of the cobalt supply chain are detailed afterwards.

Figure 16: A simplified schematic of the cobalt supply chain

After exploration and the development of mine infrastructure, cobalt is mined, mostly as a by-product of copper and nickel. Ores are concentrated, and intermediate products are produced. These are further upgraded into refined products. These are consumed in the production of various products, the most significant being lithium-ion battery cathodes. Cobalt-containing products (such as lithium-ion batteries) are consumed in a wide number of end-use applications. Lithium-ion batteries are used mainly in consumer electronics and electric vehicles. These end-use products are either recycled or disposed of. At each stage cobalt products are traded domestically and internationally, often within the boundaries of firms.



Source: Author's construction

Exploration is the geological search for economic deposits of a mineral. In the case of cobalt, almost exclusively a by-product, this search is usually a search for copper or nickel. There are two main types of exploration, brownfield and greenfield. The former refers to exploration of an area that has already been discovered. The latter relates to exploration of an area in which no historical production or geological scoping has occurred.

Cobalt is a chemical element. Pure cobalt is not found in nature, but compounds are widely distributed within the earth's crust. Over 130 minerals contain minor amounts of cobalt and around 70 minerals contain cobalt as an important constituent, but only a few occur in economic concentrations. Total world reserves are estimated by the USGS (2018) at around 7.1Mt of contained cobalt. The DRC has the largest cobalt reserves and accounts for 49% of the world total (USGS, 2018).

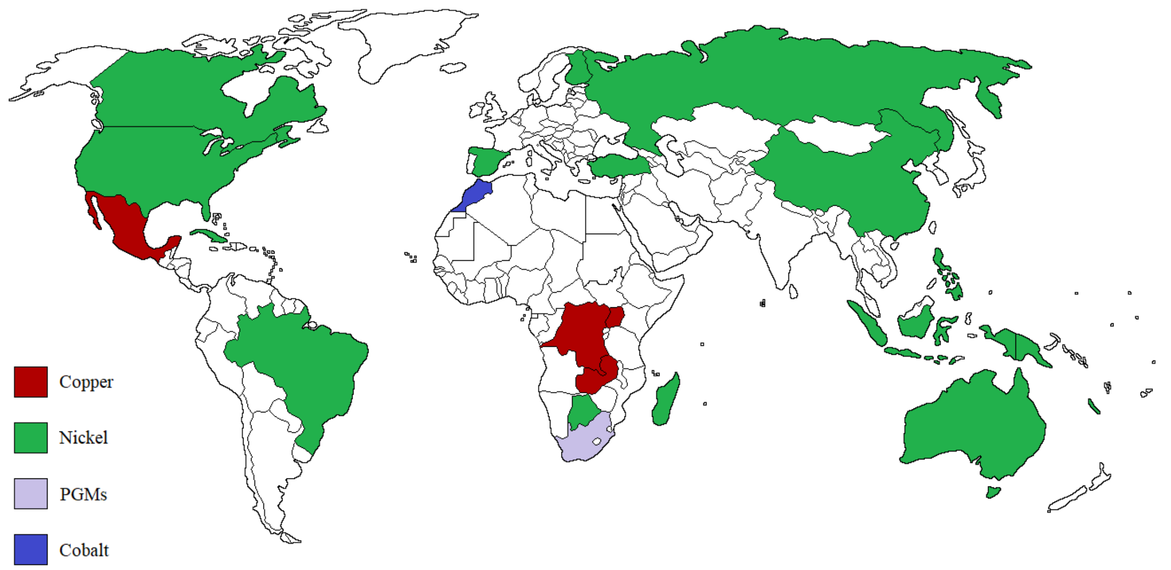
Mine production is only possible after economic concentrations of a mineral or metal are located, and the appropriate infrastructure has been developed. Dependent on size, grade, morphology and proximity to surface, cobalt deposits are either mined by underground or open-pit methods (BGS, 2009).

After mining, ores are processed to upgrade their mineral content into a more valuable concentrate. This process of beneficiation is typically carried out at the mine site.

Economic concentrations of cobalt typically occur alongside copper or nickel and thus cobalt is mostly mined as a by-product of copper or nickel mining. However, some 'primary' cobalt mine production occurs in Morocco and in South Africa, cobalt is recovered as a by-product of platinum group metal (PGM) mining. Figure 17 shows the geographic spread of cobalt mine production in 2017 and illustrates the primary product that is typically extracted.

Figure 17: Cobalt by-production in major producing countries, 2017

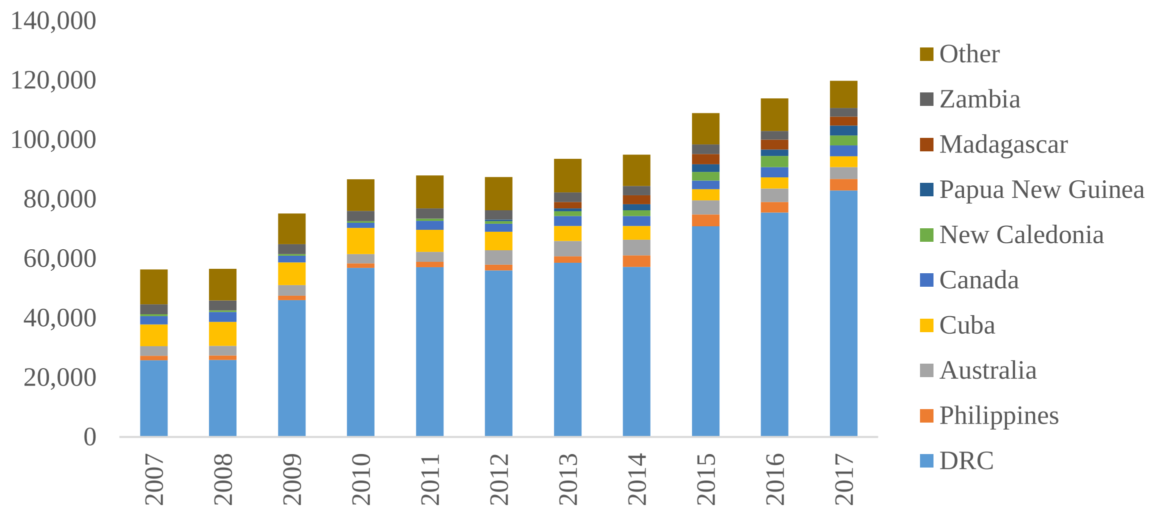
Cobalt is mined on six continents. While in tonnage terms most cobalt extraction is as a by-product of copper mining, this only occurred in four countries in 2017. Production as a by-product of nickel mining occurred in 15 countries. In some countries, such as Zambia, cobalt is produced as a by-product of both copper and nickel mining.



Source: Author's construction

The DRC is by far the world's largest mine producer of cobalt (Figure 18). Other major mine producers are the Philippines, Australia, Cuba and Canada.

Figure 18: Cobalt mine production by major producing country, 2007 to 2017

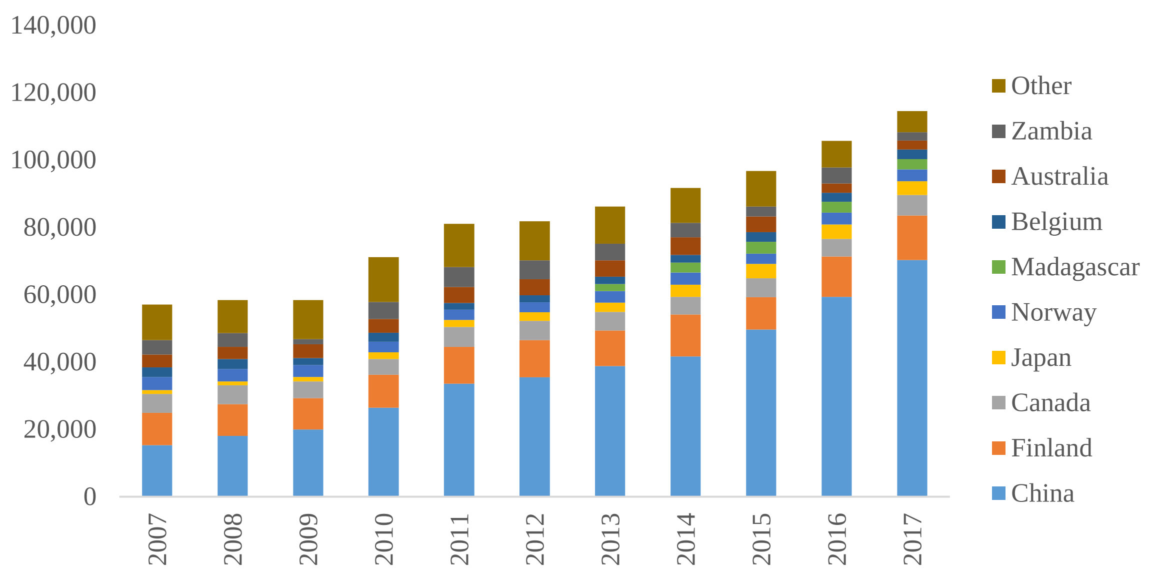


Source: Adapted from data in Roskill (2018)

Intermediate production is the next step in the linear cobalt chain. Cobalt concentrates are further processed into intermediate products. Processing for cobalt generally begins only after the primary metal has been concentrated and extracted and the processes used are often unique to the mineralogy of the ore exploited (BGS, 2009). There are three basic processes: hydrometallurgy, pyrometallurgy and vapometallurgy (BGS, 2009). There are numerous forms of intermediate cobalt product, with the most widely utilised being cobalt hydroxide and alliage blanc (if the ores have been mined as a by-product of copper) or cobalt-containing nickel mattes and precipitates (if the ores have been mined as a by-product of nickel). These intermediate products are, in turn, sent to captive refining operations in-country, or abroad, or sold to domestic or foreign refining companies (Roskill, 2018).

Refined production is the next step in the linear cobalt chain. Refined cobalt products can be split into chemical products – such as cobalt oxide and cobalt sulphate – and metal products – such as cathodes, briquettes, ingots, granules and powder (Roskill, 2018). China was by far the largest refined cobalt producer in 2017, while Finland, Canada, Australia, Belgium, and Zambia were all significant producers (Roskill, 2018). Most refined production in China is based on imported intermediate feedstock, mainly from the DRC, although some is based on Chinese intermediates, which are themselves mostly produced from imported DRC ores and concentrates.

Figure 19: Cobalt refined production by major producing country, 2007 to 2017



Source: Adapted from data in Roskill (2018)

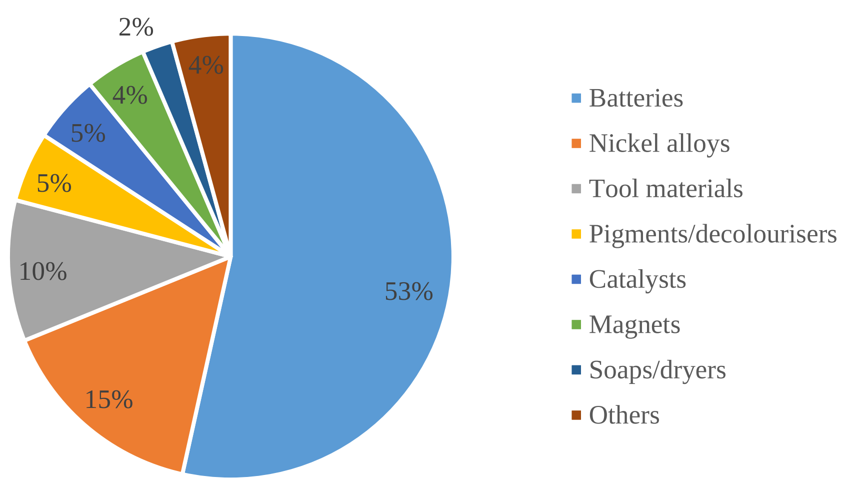
Consumption and **distribution and consumption are** the next steps in the linear cobalt chain. While in the basic linear chain for cobalt set out above, consumption is represented by two stages in the chain, in reality, there may be numerous steps, depending on the specific end-use application for refined cobalt. For example, cobalt that is eventually consumed in an electric vehicle will go through several different stages of what can be broadly termed as 'consumption'. Cobalt sulphate (a refined cobalt product) is consumed in the manufacture of a chemical precursor material. This precursor material is then consumed in the production of a battery cathode. The cathode is consumed in the production of a battery cell and pack. And the battery pack itself is consumed in the manufacture of an electric vehicle. The complexities of cobalt consumption, thus, differ according to end use.

Consumption of cobalt has increased significantly over the past 40 years. In 1977, consumption was an estimated 22.5kt (Roskill, 1979). By 2017, consumption had increased to 118kt (Roskill, 2018). Over time, the share of consumption accounted for by various end-use applications has changed substantially. In 1977, magnets were the biggest end use for cobalt, followed by nickel alloys (Roskill, 1979). Owing to a range of factors (for an overview see Abraham, 2016), demand growth for cobalt in magnets subsided with other magnetic alloys increasingly preferred. While cobalt continues to be consumed in magnets and nickel alloys, batteries are now by far the largest end use for cobalt.

Cobalt is an essential ingredient in several batteries including lithium-ion batteries. These batteries are used in numerous applications, with the biggest end-use markets being the portable electronics (laptops, phones and tablets) and transportation (electric and hybrid vehicles) sectors. Cobalt consumption in batteries has risen from below 1kt in 1996 (Roskill, 2007) to 63kt in 2017 (Roskill, 2018). Cobalt oxides, sulphate and powders are used lithium-ion battery cathode materials.

The second-largest end use for cobalt is in nickel alloys, which are both non-ferrous and ferrous alloys in which nickel is a major, though not necessarily the principal, constituent, are the second-biggest end use for cobalt. These are mostly utilised by the aerospace sector, as well as chemical/processing industries, electronics sectors and the oil and gas sector. The third-largest end use for cobalt is in tool materials. Cobalt is a constituent part of many tool steels – a variety of carbon and alloy steels that are highly suitable for tool applications. Cobalt is also used in the petrochemical and plastic industries, as both a heterogeneous and homogeneous catalyst. Other uses for cobalt include pigments and decolourisers, magnets, soaps, agricultural applications, medical applications, electroplating and electrowinning, and alloys (Roskill, 2018).

Figure 20: Consumption of refined cobalt, by end-use, 2017 (%)



Source: Adapted from data in Roskill (2018)

Cobalt consumption in these end uses is underpinned by the consumption of these end-use products across a range of industrial sectors. Asia accounts for 60% of cobalt consumption, principally because lithium-ion battery cathodes are almost exclusively produced in China, Japan and South Korea (Roskill, 2018).

Table 13: Consumption of refined cobalt by industrial sector

Batteries	Portable electronics, energy storage, power and motive applications, automotive
Nickel alloys	Aerospace, land-based turbines (energy), medical applications
Tool materials	Cutting and drillings tools (industrial, mining, oil and gas drilling)
Catalysts	Plastics production, oil and gas refining, gas-to-liquid, hydrotreating
Pigments/decolourisers	Ceramics, glass
Magnets	Aerospace, automotive electronics, medical, military
Soaps/dryers	Paints, inks, rubber adhesives
Others	Construction, agriculture

Source: Author's construction

Disposal/recycling is the final step in the linear cobalt chain. In some cases, cobalt units ultimately report to landfill. In other cases, depending on the economic viability of recovering the cobalt (and other materials) the end-use product is recycled, and cobalt units are extracted and reprocessed.

5.1.1 Key actors in the linear cobalt supply chain

Firms engaged in cobalt production can be divided into three main categories:

(1) Large TNCs such as BHP Billiton, Glencore and Vale, which domicile in a particular country but control assets in foreign countries. By way of an example, Vale, domiciled in Brazil, has stakes in cobalt mines in Canada, Indonesia and New Caledonia.

(2) Smaller companies such as Terrafame in Finland or Meta Nikel Kobalt in Turkey which tend to have operations in one jurisdiction.

(3) State-owned enterprises (SOEs) like Gécamines in the DRC, CTT in Morocco, or ZCCM Investments Holdings in Zambia, which often play an influential role in sector governance. SOE functions and influence often stretch across the mining sector and include licensing, production, revenue collection and even direct expenditure (Natural Resource Governance Institute, 2017). Given their unique institutional status and frequently high levels of authority, SOEs often operate with limited oversight and accountability (Natural Resource Governance Institute, 2017).

In most cases, several firms have equity stakes in a cobalt producing operation, with the majority stakeholder usually leading operational activities.

Further, variation in the extent to which upstream and downstream activities are integrated, or connected, produces a basic typology of cobalt producers:

a. Vertically integrated cobalt producers which undertake mine production, intermediate production, and refined production of cobalt; and

b. Non-integrated producers which undertake only one or two of these stages of production.

Type (a) cobalt producers can take several forms. They can operate fully within the boundaries of one state, operate mine operations in one state and refinery operations in another, or control upstream and downstream operations spread across different states. These cobalt producers can operate as single entities, or as joint-ventures. What's more, their mine production can sometimes be supplemented with third-party feedstock to enable increased levels of refined production.

Type (b) cobalt producers can also operate across multiple geographies while performing only one or two production functions. Again, these cobalt producers can operate as single entities, or as joint-ventures, and be private, public or state-owned (or a combination).

As part of this research, all known producers of cobalt in 2017 have been documented and are shown in the following tables.

Table 14: List of known cobalt mine operations, 2017			
Country	Company	Mine	Primary product
Australia	BHP Billiton	Leinster, Mount Keith	Nickel
Australia	First Quantum Minerals	Ravensthorpe	Nickel
Australia	Glencore (Minara)	Murrin Murrin	Nickel
Canada	Glencore	Sudbury Group, Raglan	Nickel
Canada	Vale	Sudbury Group, Thompson, Voisey's Bay	Nickel
China	Hainan Mining	Shilu	Iron
China	Jinchuan Non-ferrous Metals	Jinchang mines	Nickel
China	Shandong Jinling Mining	Jinling	Iron
China	Wuhan Iron and Steel	Daye	Iron
China	Xinjiang XinXin	Kalatongke	Nickel
China	Zhongtiaoshan Nonferrous	Zhongtiaoshan	Sulphur
China	Zibo	Various	Sulphur
Cuba	Grupo Empresarial Cubaniquel	Punta Gorda (Ernesto Che Guevara)	Nickel
Cuba	Moa Nickel JV	Moa Bay	Nickel
DRC	Bolfast	Likasi	Copper
DRC	CDM	Kambove, Luiswishi, Mikas	Copper
DRC	Chemaf	Etoile	Copper
DRC	CIMCO	Luisha	Copper
DRC	ERG	Boss, Comide, Frontier	Copper
DRC	Feza Mining	Kamoya	Cobalt
DRC	Gécamines	Kamfundwa & Kilamusembu	Copper
DRC	Groupe de Terill Lubumbashi	Big Hill	Copper
DRC	Huachin	-	Copper
DRC	Jiayuan Cobalt	MJM	Copper
DRC	Katanga Mining (Glencore)	Kamoto Group	Copper
DRC	Metals Mines	Likasi	Cobalt
DRC	MKM	Kalumbwe-Myunga	Copper
DRC	Mutanda Mining (Glencore)	Mutanda	Copper
DRC	ROQ Mining	Goma 1 and Goma 2	Copper
DRC	Ruashi Mining	Kalukuluku	Copper
DRC	Sicomines	Kolwezi	Copper
DRC	Somika	Lubumbashi	Copper
DRC	TFM	Tenke Fungurume	Copper
DRC	Volcano Mining	Unknown	Copper
Finland	Belvedere Resources	Hitura Nickel	Nickel
Finland	Terrafame	Sotkamo	Nickel
Indonesia	PT Antam	Pomalaa/Tapunopaka	Nickel
Indonesia	Vale Indonesia	Sorowako	Nickel
Madagascar	Ambatovy JV	Ambatovy	Nickel
Mexico	MMB	Boleo	Copper
Morocco	CTT	Bou Azzer	Cobalt
New Caledonia	Société Le Nickel	Thio/Kouaoua/Népoui/Tiébaghi/Poum	Nickel
New Caledonia	Vale Nouvelle Caledonie	Goro	Nickel
Philippines	Coral Bay Nickel	Coral Bay	Nickel
Philippines	Nickel Asia	Rio Tuba/Hinatuan/Taganito/Cagdianao	Nickel

PNG	Ramu NiCo	Kurumbukari	Nickel
Russia	Norilsk Nickel	Polar, Kola	Nickel
South Africa	ARM/ Norilsk Nickel Africa	Nkomati	Nickel
South Africa	Anglo American Platinum	Bushveld Complex	PGMs
South Africa	Implats	Bushveld Complex	PGMs
South Africa	Lonmin	Marikana & Limpopo	PGMs
South Africa	Northam	Limpopo	PGMs
Spain	Valoriza Mineria	AguaBlanca	Nickel
Turkey	Meta Nikel Kobalt	Gördes and Yunusemre	Nickel
USA	Lundin	Eagle	Nickel
Zambia	Barrick Gold	Lumwana	Copper
Zambia	CNM/Jinchuan	Munali	Nickel
Zambia	CNMM (NFCA and LCM)	Chambishi, Baluba, Luansjya	Copper
Zambia	Konkola Copper Mines	Nampundwe, Konkola, Nchanga	Copper
Zambia	Mopani Copper Mines (Glencore)	Mopani (Nkana & Mufulira)	Copper
Zimbabwe	Bindura Nickel Corp	Shangani, Trojan	Nickel
Zimbabwe	Mimosa Investments	Mimosa	PGMs
Zimbabwe	Zimplats Holdings	Various	PGMs
Source: Author's construction			

Table 15: List of known intermediate cobalt operations, 2017

Country	Company	Operation	Cobalt product
Australia	BHP Billiton	Kalgoorlie	Ni-Cu-Co-S matte
Australia	First Quantum Minerals	Ravensthorpe	Ni-Co MHP
Australia	Glencore (Minara)	Murrin Murrin	Ni-Co MSP
Canada	Glencore	Sudbury	Ni-Cu-Co-S matte
Canada	Vale	Copper Cliff, Thompson	Ni-Cu-Co-S matte
China	Great Power/Jinchuan	Hangzhou Gulf Industrial Zone	Co salts
China	Guanglin Chemical	-	Co salts
China	Guangxi Yinyi	Beibu Gulf Economic Development Zone	Ni-Co MSP
China	Huayou Cobalt	Tongxiang Economic Development Zone	Co salts
China	Jiangsu Changzhou KTK	Yaoguan Industrial Park	Co salts
China	Jiangsu Xiongfeng Technology	Zhengyu Industrial Park	Co salts
China	Jiangxi Rare Metal	Ganzhou Cobalt Smelter	Co salts
China	Jiayuan Cobalt	Qingting County	Co salts
China	Jilin Jien Nickel Industry	Chongqing Jien Smelting	Ni-Cu-Co-S matte
China	Jinchuan Non-ferrous Metals	Jinchuan	Ni-Cu-Co-S matte
China	Loudi Hongtaiyang	Louxing Economic and Industrial Park	Co salts
China	Nanjing Han Rui Cobalt	Jiangning	Co salts
China	Nantong Xinwei Nickel & Cobalt	Qinglonggang Chemical Park	Co salts
China	New EAR Group	Hangzhou Bay	Co salts
China	Ningbo Coboto Cobalt & Nickel	Haitu Industrial Park	Co salts
China	Ningbo Hualisi	Yuyao Chemical Factory	Co salts
China	Shenzhen GEM (KLK)	Jiangsu Taixing	Co salts
China	Sichuan FuYuZheng Mining	Guang'an Xinqiao Energy & Chemical Park	Co salts
China	Sichuan Ni&Co Guorun	Huili Copper Factory	Ni-Cu-Co-S matte
China	Tianjin Maolian	TEDA	Co salts
China	Umicore	Longzhuanshang	Co salts
China	Xinjiang XinXin	Fukang Refinery	Ni-Cu-Co-S matte
China	Yantai Cash Industrial	Xingfu, Yantai	Co salts
China	Zhuhai Kelixin Metal Materials	Zhuhai Gaolan Port	Co salts
China	Zibo Cobalt Company	Zibo Cobalt Factory	Co salts
China	Ganzhou Tengyuan Cobalt	Hongjin Industrial Zone	Co salts
Cuba	Grupo Empresarial Cubaniquel	Punta Gorda	Co oxide
Cuba	Moa Nickel	Pedro Sotto Alba	Ni-Cu-Co-S matte
DRC	CDM (Huayou Cobalt)	Lubumbashi	Co hydroxide
DRC	Chemaf	Usoke	Co hydroxide
DRC	CIMCO (China Railway)	Luisha	Co salts
DRC	Feza Mining	Likasi	Co in alliage blanc
DRC	Gécamines	Panda	Co in alliage blanc
DRC	Katanga Mining (Glencore)	Luilu Metallurgical Plant	Co hydroxide
DRC	Metals Mines (MTM)	Likasi	Co salts
DRC	Mutanda Mining (Glencore)	Mutanda	Co hydroxide
DRC	Ruashi Mining	Ruashi	Co hydroxide
DRC	Shituru Mining	Gécamines Panda-Shituru plant	Co in alliage blanc
DRC	Somika	Lubumbashi	Co hydroxide
DRC	STL	Big Hill	Co in alliage blanc

DRC	TFM	Tenke Fungurume	Co hydroxide
Finland	Norilsk Nickel	Harjavalta	Co sulphate
Indonesia	Vale Indonesia	Sorowako	Ni-Co matte
Madagascar	Ambatovy JV	Ambatovy	Ni-Co-S matte
Mexico	MMB	Boleo	Co hydroxide
Morocco	CTT	BouAzzer	Co hydroxide
New Caledonia	Société Le Nickel (SLN)	Doniambo	Ni-Co matte
New Caledonia	Vale Nouvelle Caledonie (VNC)	Goro	Co carbonate, Ni-Co MSP
Philippines	Coral Bay Nickel	Rio Tuba	Ni-Co MSP
Philippines	THPAL	THPAL	Ni-Co MSP
PNG	Ramu NiCo	Basamuk Bay	Ni-Co MHP
Russia	Norilsk Nickel	Polar, Kola	Ni-Co-S matte
South Africa	Anglo American Platinum	Rustenburg	PGM-Ni-Cu-Co-S matte
South Africa	Implats	Springs	PGM-Ni-Cu-Co-S matte
South Africa	Lonmin	Marikana	Ni-Co sulphate
South Africa	Northam	Northam	Ni-Co sulphate
South Korea	Metal Chemical Company	MCC	Co carbonate
Zambia	Chambishi Metals	Kitwe	Co in alliage blanc
Zambia	CNMM	Chambishi	Unknown
Zambia	Konkola Copper Mines	Nchanga	Co in alliage blanc
Zimbabwe	Bindura Nickel	Bindura	Co hydroxide
Zimbabwe	Zimplats Holdings Limited	Selous	PGM-Ni-Cu-Co-S matte
Source: Author's construction			

Table 16: List of refined cobalt operations, 2017

Country	Company	Operation	Cobalt product
Australia	Minara (Glencore)	Murrin Murrin	Metal
Belgium	Umicore	Olen	Chemical
Belgium	Umicore	Olen	Metal
Brazil	Vale	Port Colborne, Thompson, Voisey's Bay	Metal and chemical
Canada	Moa JV	Fort Saskatchewan	Metal
China	Great Power/Jinchuan	Hangzhou Gulf Industrial Zone	Chemical
China	Guanglin Chemical	-	Chemical
China	Guangxi Yinyi	Beibu Gulf	Metal
China	Huayi	-	Chemical
China	Huayou Cobalt	Tongxiang	Chemical
China	Hunan HaiNa	-	Chemical
China	Jiangsu Changzhou KTK	Yaoguan Industrial Park	Chemical
China	Jiangsu Xiongfeng Technology	Zhengyu Industrial Park	Metal and chemical
China	Jiangxi	Ganzhou Cobalt Smelter	Chemical
China	Jiayuan Cobalt	Qingting County	Metal and chemical
China	Jilin Jien Nickel Industry	Songhua Riverside	Metal
China	Jinchuan Non-ferrous Metals	Jinchuan Nickel Complex	Metal and chemical
China	Loudi Hongtaiyang	Louxing	Metal and chemical
China	Nanjing Han Rui Cobalt	Jiangning	Metal and chemical
China	Nantong Xinwei	Qinglonggang Chemical Park	Metal and chemical
China	New Era Group	Hangzhou Bay	Chemical
China	Ningbo Coboto	Haitu Industrial Park	Chemical
China	Ningbo Hualisi	Yuyao Chemical Factory	Metal and chemical
China	Shenzhen GEM	Jingmen High-tech Industrial Zone	Metal and chemical
China	Shenzhen GEM (KLK)	Jiangsu Taixing	Metal and chemical
China	Sichuan FuYuZheng Mining	Guang'an Xinqiao	Metal and chemical
China	Sichuan Ni&Co Guorun	Huili Copper Factory	Metal
China	Tianjin Maolian	TEDA	Chemical
China	Umicore	Longzhuanshang	Metal and chemical
China	Wanbao	-	Metal
China	Xiamen Tungsten	Xiamen	Chemical
China	Xinjiang XinXin	Fukang Refinery	Metal
China	Yantai Cash Industrial	Xingfu, Yantai	Metal and chemical
China	Zhuhai Kelixin Metal Materials	-	Chemical
China	Zibo Cobalt Company	Zibo Cobalt Factory	Chemical
China	Ganzhou Tengyuan Cobalt	Hongjin Industrial Zone	Chemical
DRC	Chemaf	Etoile/Usoke	Metal
DRC	Gécamines	Shituru	Metal
DRC	Katanga Mining (Glencore)	Luilu Metallurgical Plant	Metal
Finland	Freeport Cobalt	Kokkola	Metal and chemical
France	Eramet	Havre-Sandouville	Chemical
India	Nicomet	Goa	Metal and chemical
India	Rubamin	Baroda	Metal and chemical
Japan	Sumitomo Metal Mining	Niihama	Metal
Madagascar	Ambatovy JV	Ambatovy	Metal

Mexico	MMB	Boleo	Metal
Morocco	CTT	Guemassa	Metal
Norway	Glencore	Nikkelverk	Metal
Russia	Norilsk Nickel	Polar, Kola	Metal
South Africa	Anglo Platinum	Rustenburg	Chemical
South Africa	Implats	Springs	Metal
South Africa	Shu Powders	Durban	Metal
South Korea	Metal Chemical Company	-	Chemical
South Korea	Metal Chemical Company	-	Metal
Uganda	Kasese Cobalt	Kilembe	Metal
UK	Vale	Clydach	Metal and chemical
USA	GTT	-	Metal
Zambia	Chambishi Metals	Kitwe	Metal
Zambia	Mopani Copper Mines	Nkana	Metal
Source: Author's construction			

5.2 A GPN for cobalt

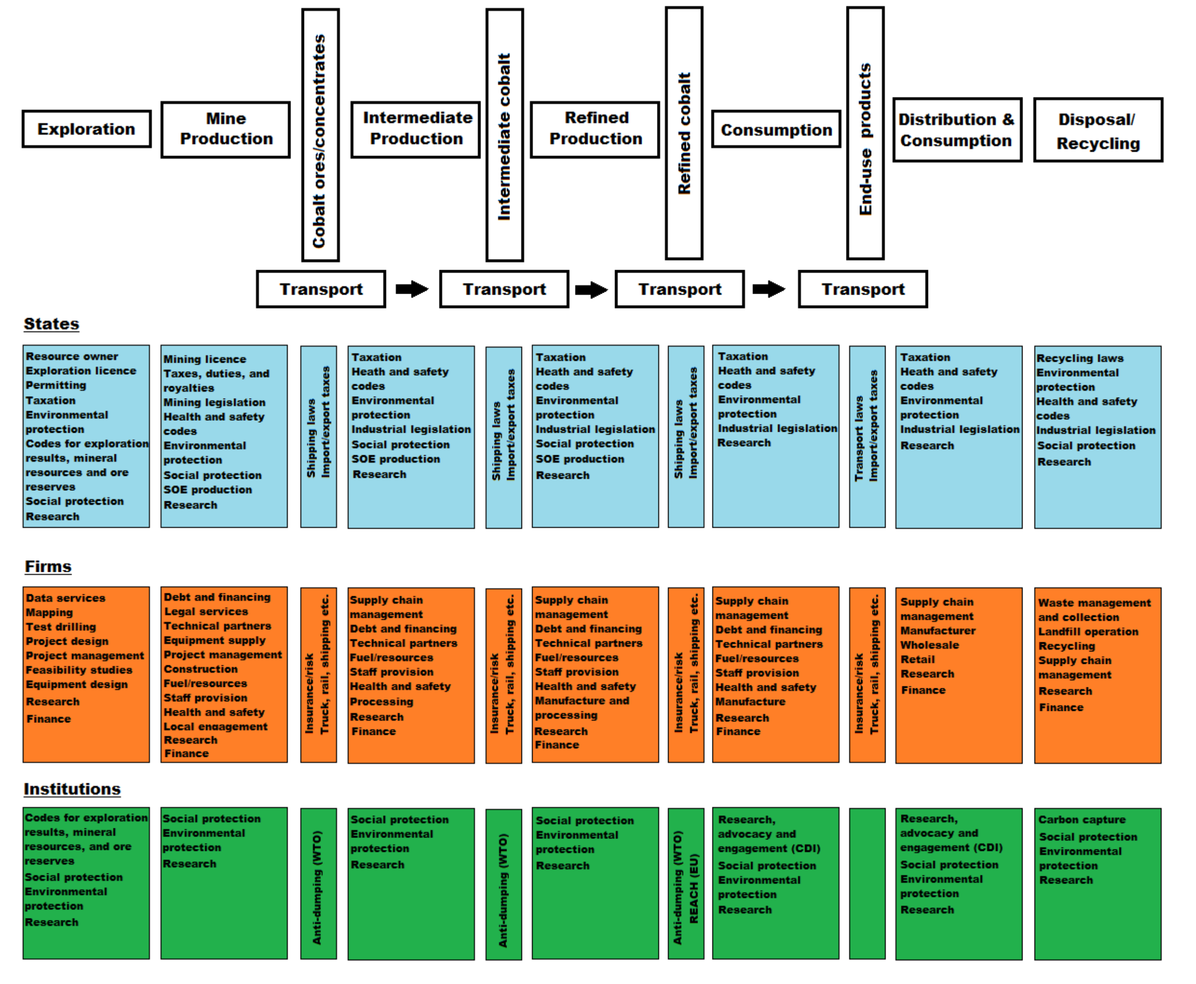
The description of the cobalt supply chain presented above is useful for providing an understanding of the way cobalt is materially transformed across various stages. Viewing the cobalt chain in this way also provided an opportunity for outlining the various firms engaged in the supply chain. However, this linear view of cobalt production and consumption, while illuminating, fails to capture the all of various actors and dynamics that underpin the cobalt chain and falls short of explaining how the sector is structured and coordinated. Similar criticism has been levelled at global commodity chain and global value chain approaches generally, as they are guilty of underplaying the importance of geographically specific conditions and firm and non-firm dynamics (Coe and Yeung, 2015).

Global production network thinking, however, encompasses a focus on the key actors involved and focusses on the numerous geographies bound together by the economic relations born of actor-specific firm and non-firm strategies. As such, following a similar approach to that set out in existing studies of raw materials GPNs (Bridge, 2008; Bridge 2017; Gibson and Warren; 2016), the GPN approach is extended to the cobalt sector below. In choosing this approach as appropriate for characterising outcomes in the cobalt sector, this research agrees with the justification put forward by Knierzinger (2018) that the connection between GPNs and the extractive sector have already been established by several studies, and that GPN thinking is the last offspring and thereby the most topical label of commodity-based approaches (Knierzinger, 2018 p.40).

A generalised global production network for the cobalt sector is shown in Figure 21. In the white boxes at the top of the schematic, the same linear cobalt chain discussed above, and presented in Figure 16, is visible. The analysis that follows Figure 21 explores the various roles of states, firms and institutions in the cobalt GPN.

Figure 21: A generalised global production network for the cobalt sector

This generalised global production network for cobalt outlines the various roles and processes undertaken by different actors in the cobalt network.



Source: Author's construction

States are incorporated into the global production network for cobalt in a number of different ways. First, as the main resource owner, the state is responsible for granting access to mineral resources. This gives states a considerable degree of governance over the upstream part of the chain – through the granting of exploration licenses and related permitting and taxation at the exploration stage, and through the granting of mining licenses and control of taxes, duties and royalties at the mine production stage.

Second, the state is responsible for social and environmental protection practices and related taxation, giving it an important regulatory role at the exploration and mine production stages. Furthermore, the state is ultimately responsible for health and safety and industrial codes which spread across the upstream and downstream parts of the chain.

Third, the state operates mine facilities in a number of jurisdictions through state-owned mining enterprises or joint-venture operations with private/public companies. In some cases, state-owned or part-state-owned companies control mines in foreign jurisdictions. For example, this is the case with MKM, which operates the Kalumbwe-Myunga mine in the DRC. MKM is owned in part by China Overseas Engineering Group, a Chinese construction and engineering company which is subsidiary of China Railway Engineering Corporation, itself a state-owned holding company of China, under the supervision of the State Council.

Fourth, the state usually controls import and export legislation and taxation, which considerably impacts production network dynamics through creating (or removing) logistical and financial barriers and constraints. Fifth, states play an important regulatory role in the downstream chain with regard to recycling and disposal or raw materials. Finally, state-led research into both upstream and downstream parts of the sector is important in some jurisdictions.

The global production network for cobalt illuminates the importance of the role of the state across the cobalt chain. States are important actors in the upstream and downstream phases of the cobalt chain, highlighting how production networks are highly territorial. Importantly, the pervasive role of the state has the potential to bring out numerous operational supply risks. The territorial embeddedness of raw materials such as cobalt, in combination with the degree of governance that states can exercise over the upstream part of the chain, creates numerous scenarios in which state activity can lead to supply disruption. It is partly for this reason that the critical materials literature focusses so much on dependence on supply from countries with poor governance. It is not only mining-related state activity (such as the granting or rescinding of mining licenses) that can impact raw material flows. Regulatory policies, such as environmental or social protection measures, can also create operational supply risks. This serves as a useful example, as it evidences the fact that good governance measures (such as social protection) could have negative consequences for raw material supply, and, therefore, that concerns over supply risk should not be limited to countries in which governance is deemed to be poor.

Institutions represent another non-firm actor which play a number of important roles in the cobalt global production network. First, codes for mineral reserves and resources usually conform to state- or institution-level conventions. For example, the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code) is a professional code of practice that sets minimum standards for public reporting of minerals exploration results, mineral resources and ore reserves.

Second, international trade is, to an extent, bound by contracts, guaranteeing countries important trade rights. The World Trade Organisation's (WTO) agreements, negotiated and signed by a large majority of the world's trading nations, and ratified in their parliaments, can be considered as rules governing international commerce. As the WTO has about 160 members, which together account for 95% of world trade, its rules significantly impact cobalt trade. Third, institutions play an important role in promoting co-operation, fair trade and undertaking cobalt –related advocacy work. The key trade association most relevant to cobalt is the Cobalt Institute (CI), a non-profit trade association composed of producers, users, recyclers, and traders of cobalt. The CI promotes the sustainable and responsible production and use of cobalt in all its forms. There has been some form of cobalt institution in existence since 1957 and the present CI has 20 members from 14 countries including all the major cobalt producers. Fourth, international institutions play an important role in the cobalt sector by promoting human rights, and environmental and social protection. In recent years there has been a glut of research on the DRC cobalt and copper sectors (Amnesty International, 2016; Global Witness, 2004; Global Witness, 2009; Nordbrand and Bolme, 2007; Peyer, 2011; Scheele et al., 2016; Tsurukawa et al., 2011). Fifth, cobalt trade is governed by binding international rules set out by institutions. For example, the Registration Evaluation Authorisation and restriction of Chemicals (REACH) policy affects all producers, manufacturers, importers and downstream users of chemicals in the EU. REACH aims to ensure that those in industry, and the public, are not negatively affected by chemical manufacture and trade. Three REACH Consortia have been established by the Board of the CDI to implement on behalf of the cobalt industry, with the purpose of preparing the registration dossiers for cobalt and cobalt compounds. A separate wholly-owned subsidiary of the CDI called the Cobalt REACH Consortium (CoRC) acts as secretariat to the consortia.

The global production network for cobalt also offers new insights into the role of **firms**. While chain theories tend to consider firms as producers and consumers, the global production network framework highlights how firms undertake a wide range of other functions. For example, at the exploration stage firms undertake data services, mapping, drilling, project design, project management, financing, legal services, equipment design etc. Firm-level cobalt production activities are best conceptualised as network interactions comprised of a wide number of inter-firm linkages. For example, a mining project undertaken by TFM in the DRC will incorporate mapping produced by a third-party, drilling which can be contracted to external parties etc. Unlike other approaches, "…a global production network entails the central role of one globally significant lead firm, and its organisational coordination and control and territorial configuration of a sufficient number of intra-firm affiliates, strategic partners, suppliers, customers, and extra-firm institutions" (Coe and Yeung, 2015, p.39). A lead firm should be clearly identifiable within a particular industry which may be characterised by the existence of multiple lead firms (Coe and Yeung, 2015, p.39). Examples of lead firms in the automotive sector are Volkswagen and BMW. Information technology examples are Apple and Google. In the cobalt sector, there are firms that can be said to coordinate and control the sector (for a list see Table 6). Perhaps the most important are Glencore and Huayou Cobalt. Glencore is the world's biggest producer of cobalt in tonnage and value terms, undertakes all stages of cobalt production, and has cobalt production sites in more countries than any other firm (Australia, Canada, the DRC, Norway, Zambia). Huayou Cobalt which, as set out in the case study in chapter 7.2.1, has grown to become the world's largest refined cobalt producer. Notably, when it began operating in 2002, Huayou Cobalt was engaged in only one stage of the cobalt supply chain (refining). But through a series of investments, the company integrated backwards, investing in DRC cobalt mine and intermediate production facilities to bring the production of cobalt feedstock within the boundaries of the firm. More recently, the company has moved to integrate forwards and produce lithium-ion battery precursors and cathodes rather than sell its refined cobalt products to external firms. It has also started recycling cobalt.

5.3 Using the GPN analytical toolkit

Chapter 5.1 conceptualised the cobalt sector as a linear production chain, which proved useful in explaining the different stages of production and consumption and the key firms, and types of firms, involved. The analysis set out in chapter 5.2 utilised the GPN framework to better understand the roles played by firm and non-firm actors in the cobalt chain. By foregrounding institutions and states in particular, as well as firms, it served to highlight the diversity of organisational forms. In this subchapter, the research borrows tools from the GPN analytical toolkit to further explore outcomes and begin to understand behaviours in the cobalt sector.

5.3.1 Value

GPN thinking is concerned with how actors create, enhance and capture value. The creation and subsequent capture of value can be considered the 'purpose' of a global production network (Coe et al. 2015). The term 'value' is used broadly to refer both to the surplus value created during the process of production and the different types of economic rent realised within production networks when payment is made to or for a factor of production in excess of the costs needed to bring that factor into production. In the cobalt GPN, surplus value is created through the production process as cobalt units are converted into higher-value cobalt-bearing products. Inputs, such as labour and cobalt raw materials, are converted into cobalt products that can be sold for more than the value involved in their creation.

Economic rent arises from a condition of scarcity, when a firm has access to resources that others do not and can take various forms. Of relevance to extractive sector production networks is resource rent, when firms have control or access to natural resources that others do not. Further, expertise in or access to infrastructure, production processes, or beneficial government policies are also highly relevant resources in extractive sector networks.

As in all extractive sector GPNs, resource rent is a key feature of the cobalt GPN. States, through virtue of favourable geology, and firms, through ownership arrangements with states, have access to finite cobalt resources that others do not and as such can ultimately capture value directly or indirectly from the extraction of cobalt raw materials from the earth's crust and their subsequent transformation into demanded cobalt goods. In the cobalt GPN, where several stages of production are undertaken in the linear chain, there are various stages of value enhancement and capture and cobalt units are upgraded multiple times before becoming ingredients in consumer items. In most cases, value is not captured where it is initially created. At the upstream part of the cobalt chain, initial value creation, enhancement and capture activities are governed by geology and take place close to a mine. However, other activities further down the linear chain are shaped more by factors such as access to infrastructure, production processes, and beneficial government arrangements. With China accounting for a high proportion of refined cobalt production, lithium-ion battery production, consumer electronics production and electric vehicle manufacture, a high proportion of the value created in the cobalt chain is ultimately captured in China. This is the result of numerous factors, including the desire of Chinese firms to capture value in country as opposed to abroad, as well as the skills, knowledge base and infrastructure in China related to cobalt processing.

5.3.2 Power

Power is an important element in the organisation, coordination and control of global production networks. In GPN thinking, power effectively relates to an actor's ability to influence another actor to the latter's disadvantage. The GPN framework encapsulates corporate power, collective power (labour, unions etc.) and institutional power (e.g. international institutions). Power is seen as relational and transaction specific, varying between actors and their resources (Coe et al., 2015).

Power in the cobalt network is strongly influenced by an actor's control of cobalt assets or cobalt units. Power is relational to the extent to which such units or assets are sought after, or demanded, by other actors in the network. In extractive sectors GPNs, scarcity is an important factor in power relations. Power is concentrated in the hands of actors with access to scarce assets. Actors who have homogenous, ubiquitous assets or produce commodity products, have less power.

Power relations change over time in GPNs. In raw material market GPNs, shifting supply-demand (and price) dynamics have a fundamental impact on the power relations between actors. In the cobalt GPN, producers of cobalt have more power during periods of high demand for cobalt. At such times, the products that they produce are desirable to more actors and command a higher price. During periods of low demand, consumers of cobalt have more bargaining power with producers, especially regarding prices. Power relations change over time for other reasons too. As Coe et al. (2015) note, firms can upgrade their assets and competencies and as such the power relations between distinct actors can alter over time. A small cobalt producer can increase its scale, for example, or begin to produce a wider range of cobalt products.

Several types of power are important in the cobalt GPN. As well as corporate power, collective power is important. This may refer to such entities as unions or civil society organisations which, at times, have had considerable power over firms and even states. For example, union action at a cobalt mine has, in the past, caused certain operations to shut down temporarily.

Institutional power relationships are also important. Institutional power can refer to both the power held by states as well as global institutions. Global institutions certainly have some sway in the cobalt GPN. For example, the WTO has powers to set global trade rules and norms. Another example is that the EU's REACH regulations ban the import of certain forms of cobalt chemicals into Europe.

States are a key actor and power holder in an extractive sector GPN. Resource-holding states hold considerable sway over firms in extractive sectors, given their various roles including regulator, tax collector and resource allocator. Again, such power relations are temporal. Under certain market conditions, states have more power over firms. Returning to the example of a period of high demand for cobalt, under such circumstances a state's power over a resource-seeking firm is more significant as the value of the scarce cobalt asset is higher. However, when there is little demand for cobalt, cobalt-bearing mineral deposits are less valuable and as such the power a state can exercise over a resource-seeking firm is less significant. Firms can also have considerable power over states as has been the case at times in the cobalt GPN. For example, some states have required investment has certain powers over states. Ultimately, power relations between firms and states, and firms and firms are rarely as simple as the conventional wisdom tends to suggest whereby the large automatically dominate and exploit the small – indeed they are instead case specific, not structurally determined and are unidirectional (Coe et al. 2015).

While not outlined in the literature, *supply chain power* can also be considered an important type of power in the cobalt network. Vertical integration is a key element of extractive sectors GPNs and can provide security of supply and cost advantages. A vertically integrated supply chain gives actors within it a form of supply chain security that, under most market conditions, leads to beneficial power relations with those outside of the chain.

5.3.3 Embeddedness

There are two interrelated forms of embeddedness employed within GPN thinking. Network embeddedness is concerned with network structure and the connectivity within a GPN. Territorial embeddedness refers to how actors are located in different spaces. This is because of an actor's dependence on resources, materials, labour etc., located in particular places.

Global production networks are discontinuously territorial (Henderson et al., 2002). They do not exist in an anonymous space but are territorially embedded in multiple regions (Lane and Probert, 2009). This is, of course, true of the cobalt GPN which touches down on six continents albeit heavily 'grounded' in two countries, the DRC and China. GPN thinking takes territoriality seriously because "…the 'where' question is extremely important in understanding how value creation, enhancement, and retention through global production networks matter for economic development in an interconnected world economy" (Coe and Yeung, 2015, p.67).

In their exploration of the LNG gas sector, Bridge and Bradshaw (2017, p.219) note that while it has long been acknowledged within GPN research that global production networks are spatially fragmented and 'discontinuously territorial', the problem of 'global shift' – i.e. how the territorial configuration of production networks evolves in relation to the generation and capture of value – has not been a core research focus in recent years. Bridge and Bradshaw (2017, p.19) suggest that the analytical value of territoriality is that it both foregrounds the particularity of a network's territorial configuration (why this spatial form, why now?), and links this form to strategic intent (for what ends, with what effects?). As such, territoriality encompasses both the structure of a production network and the practices, activities and behaviours of network actors that have led to this territorial outcome. Territoriality thus reflects both territorial outcomes and formation processes. Or put another way, in the words of Bridge and Bradshaw (2017), territoriality is constitutive of markets rather than merely responsive to them.

Territoriality matters in the cobalt GPN. On a structural level, all cobalt producing- and consuming actors are physically grounded somewhere. Perhaps the most important territorial feature of the cobalt GPN is the fact that, for reasons of geology, so much of the network touches down in the DRC. But moreover, and further to the argument of constitutively set out by Bridge and Bradshaw (2017), this geological reality creates and shapes patterns in the wider network. Value creation, enhancement, and retention in the wider production network are influenced by the cobalt GPNs territorial embeddedness in the DRC and the cobalt GPN's organisational and network structures are shaped by its DRC linkages. For example, both sprawling global trade networks and NGO and media opposition (also a feature of the cobalt GPN) are created by virtue of the fact that the DRC government allows widespread artisanal mining in poor conditions. The fact that the cobalt GPN touches down in the DRC creates these aspects of the network.

Like power relations, territorial forms change over time as has been the case in the cobalt GPN. Over the past two decades, there has been a move Eastwards as more and more cobalt sector value capture has occurred in China and other Asian countries. The actions of firms in the cobalt network have shaped the network's current territorial form.

5.3.4 Materiality

There have been recent calls in the literature on global production networks to pay greater attention to the importance of material transformation and the influence materiality exerts on industrial organisation (see Bridge, 2008; Ciccantell and Smith, 2009; Dougherty, 2013; Gibson and Warren, 2016; Hudson, 2008; Pereira dos Santos and Milanez, 2016). As Bridge and Bradshaw (2017) note, the central provocation of these accounts is that the heterogeneity of materials and the variability of biophysical processes enables and shapes a production network's spatial and organisational form in ways that are economically significant, yet underappreciated.

Material transformation is, of course, somewhat fundamental to the extractive sector in which metals and minerals are extracted and upgraded (or transformed) in order to capture value. Focussing attention on the importance of materiality in global production networks emphasises how production networks are organised around moments of material transformation, in which the (biological, chemical, physical) qualities of materials shape strategies for value capture (Bridge and Bradshaw, 2017). Such a focus can uncover how material forms and qualities shape the spatial and organisational configurations of networks. For example, Ciccantell and Smith (2009) noted that as materials and fuel are often bulky, both require the development of large, often very ecologically destructive infrastructural and transport systems to evacuate them from areas where natural resources are found. This serves as an example of material qualities shaping the production network. Another example is from Gibson and Warren's (2016) study of timber and acoustic guitar making, which found that the need for, and use certain hardwood timbers in acoustic guitar building influenced upstream resource geographies. A third illustration is Bridge and Bradshaw's (2017) investigation of the LNG market, in which the authors show how the material properties of LNG enable it to be distributed by means other than by the traditional gas pipeline, creating new opportunities for value capture.

Materiality is an important element in the organisation and structure the cobalt GPN. The cobalt network is organised around moments of material transformation and material forms and qualities shape the configuration of the network. A useful example is that of cobalt being mainly a by-product of copper or nickel. Depending on this geological setting, different processing options are required. Cobalt units derived from copper mines are, for the most part, transformed into a cobalt hydroxide, shipped to China, converted into a refined chemical product, and ultimately consumed in electronics and electric vehicles. Cobalt units derived from nickel mines, however, are typically processed into a matte or precipitate and upgraded into a cobalt metal product. Thus, materiality shapes the destiny of cobalt units from the point of its extraction. There are countless other instances of materiality impacting the structure of the cobalt network. For example, certain forms of cobalt metal make the material suitable for only certain applications. It is possible to dissolve all forms of cobalt metal into a chemical for use in batteries, for example, but cut cathode is more challenging. Transforming cathode into a cobalt chemical would require nitric acid which is expensive and difficult to use. As such, the material form of cut cathode shapes its eventual end use.

Materiality has various other impacts on the structure and geographies of the cobalt GPN. For example, a Chinese preference for the import of cobalt hydroxide as opposed to more bulky ores and concentrates has led to the development of numerous hydroxide plants in the DRC. Such a change has required new infrastructure in the DRC but also impacted global shipping and other transport infrastructure.

5.3.5 Strategic coupling

The concept of strategic coupling is used to explain the process of how a regional economy, or regional actors, integrate themselves into GPNs in a mutually beneficial way. Strategic coupling can be defined as a "…mutually dependent and constitutive process involving shared interests and cooperation between two or more groups of actors who otherwise might not act in tandem for a common strategic objective" (Yeung, 2009: 332).

Global production network analysis posits that the key locus for understanding economic development is the sub-national region, as actors are grounded in particular places, not national economies, which have distinctive institutional conditions that shape development practices and processes (Coe and Yeung, 2015). Thus, it is useful to focus on the sub-national level and the former Katanga province in the DRC, home to most of the world's cobalt reserves and resources, makes for a useful example.

A cobalt sector example of strategic coupling is as follows: Glencore touches down in the southern DRC as this complements its strategic needs as lead firm (in this case access to copper and cobalt units). Glencore, engages in bargaining and cooperation with regional and national institutions in the DRC and this, in turn, has developmental outcomes. These can be positive and negative. For example, Glencore asserts that its DRC investments had created over 22,000 employee and contractor jobs at the end of 2017, almost all held by DRC nationals and that between 2015 and 2017 it had paid US$1.1Bn in taxes and royalties (Glencore, 2019). However, there can also be said to have bene negative developmental outcomes. For example, Glencore has been implicated in a court case in which families argue in their claim that their children were working illegally at mines owned by Glencore (Guardian, 2020).[1]

MacKinnon (2012) went beyond the idea of strategic coupling and introduces a wider range of coupling processes such as recoupling and decoupling that take place between regions and GPNs. The central point is that coupling isn't necessarily permanent. Glencore in the DRC serves as a useful example of this. As will be shown in chapter 7.1.1.4, Glencore has over time sought to increase its ownership stakes in its DRC operations. In 2016, Glencore increased its stake in Katanga Mining to 85% and its stake in Mutanda Mining to 100%. This could be perceived as further coupling. However, in 2019 it was announced that Glencore plans to shut its Mutanda mine for a period of two years. The closure is related to poor market conditions, but also because of changes to royalty payments implemented by the DRC government (Clowes and Biesheuvel, 2019). This could be perceived as an uncoupling based on, among other factors, a breakdown in the shared interests and cooperation between Glencore as a lead firm and regional and national institutions.

This example, like the strategic coupling literature more broadly, brings into question the priorities of GPN actors and institutions, together with their agency and capabilities at any given point in time. Some contributions have explored what they term the 'dark side' of strategic coupling (see Coe and Hess, 2011; Dawley, 2011; MacKinnon, 2012). This term refers to the negative consequences of power asymmetries between partners and includes corporate capture of regional institutions and the negative impacts of corporate restructuring, stemming from power asymmetries favouring firms (Rutherford et al. 2018). There are a number of examples that could be said to represent that dark side of strategic coupling in a cobalt sector, DRC context. A notable example of the negative consequences of power asymmetries between partners is the case of First Quantum Minerals (FQM) which had its DRC cobalt

[1] Apple, Google, Dell, Microsoft and Tesla have been named as defendants in a lawsuit filed in Washington DC by human rights firm International Rights Advocates on behalf of 14 parents and children from the DRC (Kelly, 2019)

assets seized by the DRC government. This is examined chapter 8.2 of this dissertation which explores resource nationalism in the cobalt sector.

Processes of coupling, uncoupling, and recoupling have an important bearing on the organisation and structure the cobalt GPN. These processes, and the behaviours and motivations that prompt them, ultimately shape the structure and geographies of the cobalt GPN over time.

5.4 Summary

This chapter was designed to explore RQ (1) which asked: how is the cobalt supply chain structured and coordinated? Coe and Yeung (2015) define global production networks as an "…organisational arrangement, comprising interconnected economic and non-economic actors, coordinated by a global lead firm, and producing goods or services across multiple geographical locations for worldwide markets. For the purposes of this dissertation, this definition was reframed into a basic hypothesis:

The cobalt supply chain is a network of connected economic and non-economic actors, coordinated by a global lead firm, and producing goods or services across multiple geographical locations for worldwide markets.

The preceding analysis serves to confirm this hypothesis. The linear conceptualisation of the cobalt chain set out in chapter 5.1 outlined the various firm-level actors involved in the cobalt sector and detailed the various geographies of production and consumption. The extension of the GPN approach to the cobalt sector set out in chapter 5.2 went further, outlining the coordinating role of lead firms as well as the impact of non-firm actors such as institutions and states. The use of key concepts from the GPN analytical toolkit applied in chapter 5.3 showed how processes of value creation, enhancement and capture, power relations, degrees of territorial embeddedness and materiality are key coordinating and structurally relevant features of the cobalt network.

Enabling an understanding of the coordinating, organisational and controlling forces at play in a global supply chain, as well as the importance of inter-firm relations as well as firm–state relations, is highly useful in a critical material sector setting. As outlined in the introduction, what is missing from the current policy debate over extractive industries, and the literature on critical materials is a sense of the relational way in which production is organised via inter-firm and extra-firm networks that massively exceed the boundaries of the nation-state (Bridge, 2008; p.393). This analysis has served to move analysis of the cobalt sector beyond the realms of linear conceptualisation and mere definition and placed it within a framework where the causal mechanisms underpinning and shaping sectoral patterns can be explored. This will be the focus of Part III of this dissertation.

Additional discussion of the findings of this chapter and the viability of using a GPN approach in this context can be found in the conclusion.

6. An ITN approach to charting the reconfiguration of the cobalt supply chain

The previous chapter examined the structure and organisation of the cobalt supply chain. This chapter investigates how the spatial structure and geographies of the cobalt sector have changed over time. It does so by making use of available trade data to explore the evolving interdependencies between countries involved in the cobalt supply chain.

The chapter examines the International Trade Network (ITN) for cobalt units, to show the evolution of import-export relationships between all countries engaged in cobalt trade over time. The time period examined is 2007 to 2017. As noted in the literature review, analysis of the ITN has typically involved the examination of international trade flows using graph-theoretic structures where countries (vertices, or nodes) are linked by edges or links (representing the value/volume of a trade) to show import-export relationships between countries (Bhattacharya et al., 2007; Benedictis & Tajoli, 2011; Abbate et al., 2012). Some studies have taken a commodity-specific approach (also referred to as a multi-network approach) to the analysis of the ITN (Reichardt and White, 2007; Paulette et al., 2009; Barigozzi et al., 2010; Fernandez et al., 2011; Klimek et al, 2015). These studies employed data on specific commodity classes to identify stylised facts about the ITN.

There has, to date, been no study of the cobalt ITN. Indeed, there have been very few studies of commodity-specific ITNs and hardly any focussed on only one metal or mineral. This presents an opportunity to uncover detailed, stylised facts about the architecture of the cobalt trade network for the purposes of this research. Examining the 'cobalt ITN' will enable an analysis of the temporal changes to the interdependencies that exist between countries importing and exporting cobalt units, which in turn can be used as a basis to better understand how cobalt's criticality has brought about a reconfiguration of the cobalt supply chain. It also presents the opportunity to explore the viability of an ITN approach to the analysis of a single commodity class and the benefits and weaknesses of doing so.

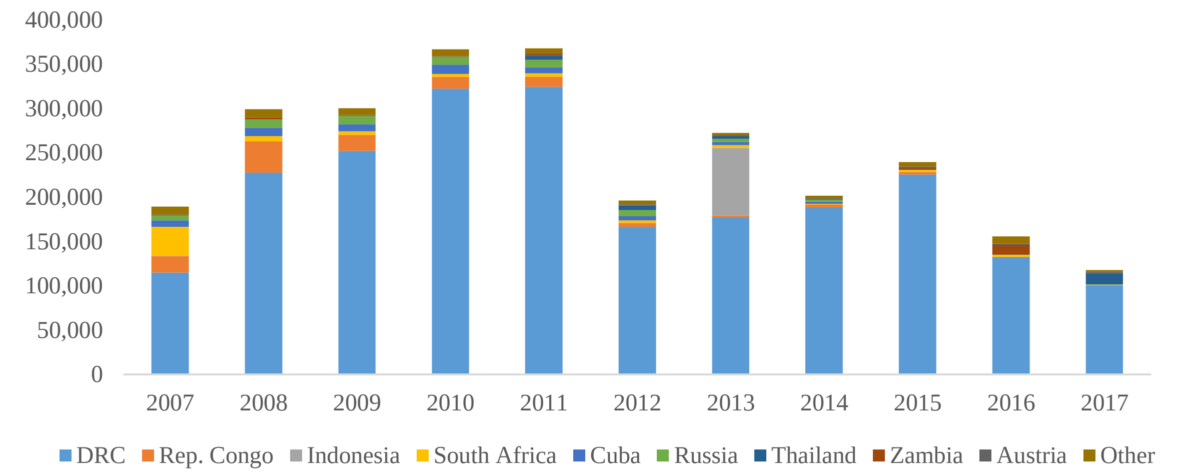
Chapter 6.1, Chapter 6.2, Chapter 6.3, and Chapter 6.4 set out four cobalt ITNs for cobalt ores and concentrates, cobalt intermediates, refined cobalt chemicals and refined cobalt metal respectively.

Chapter 6.5 considers the findings of the preceding analysis in light of the research questions and hypotheses set out in Part I of this dissertation. The chapter addresses RQ2: How has the spatial structure of the cobalt sector changed over time?

6.1 How has the cobalt ores and concentrates ITN changed over time?

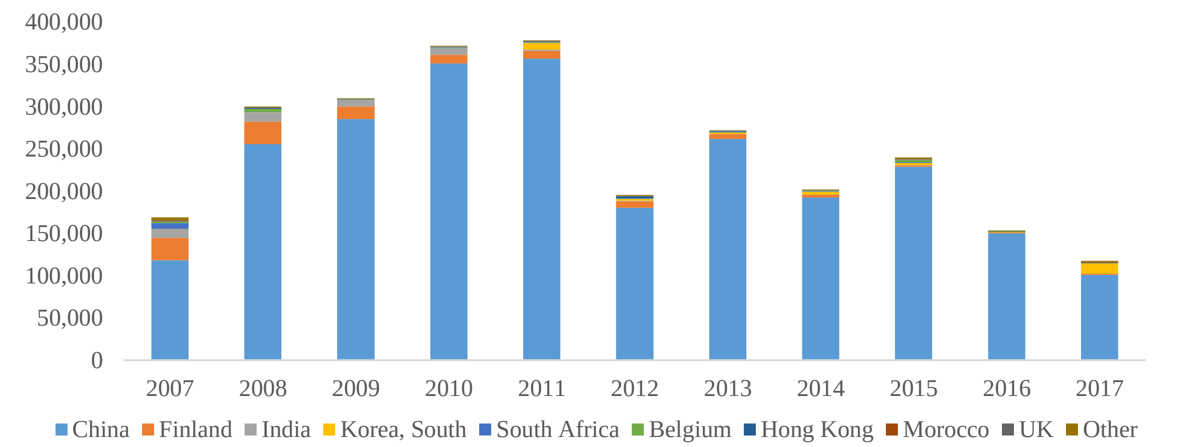
This sub-chapter sets out an ITN for cobalt ores and concentrates trade. To introduce the key importing and exporting nodes involved in the ITN, Figure 22 and Figure 23 show exports and imports of cobalt ores and concentrates respectively. A downward trend is observed over time, with 2017 representing the lowest levels of trade in tonnage terms. The DRC is by far the world's biggest exporter of cobalt ores and concentrates, while China is the largest importer.

Figure 22: Exports of cobalt ores and concentrates, by country, 2007 to 2017 (t, gross weight)



Source: Global Trade Tracker, HS Code 260500

Figure 23: Imports of cobalt ores and concentrates, by country, 2007 to 2017 (t, gross weight)



Source: Global Trade Tracker, HS Code 260500

Table 17 summarises key data for the cobalt ores and concentrates ITN over the 2007 to 2017 period. The number of countries (nodes), instances of trade between countries (links), and the resultant network density are presented for each year under analysis.

Table 17: Cobalt ores and concentrates ITN summary statistics

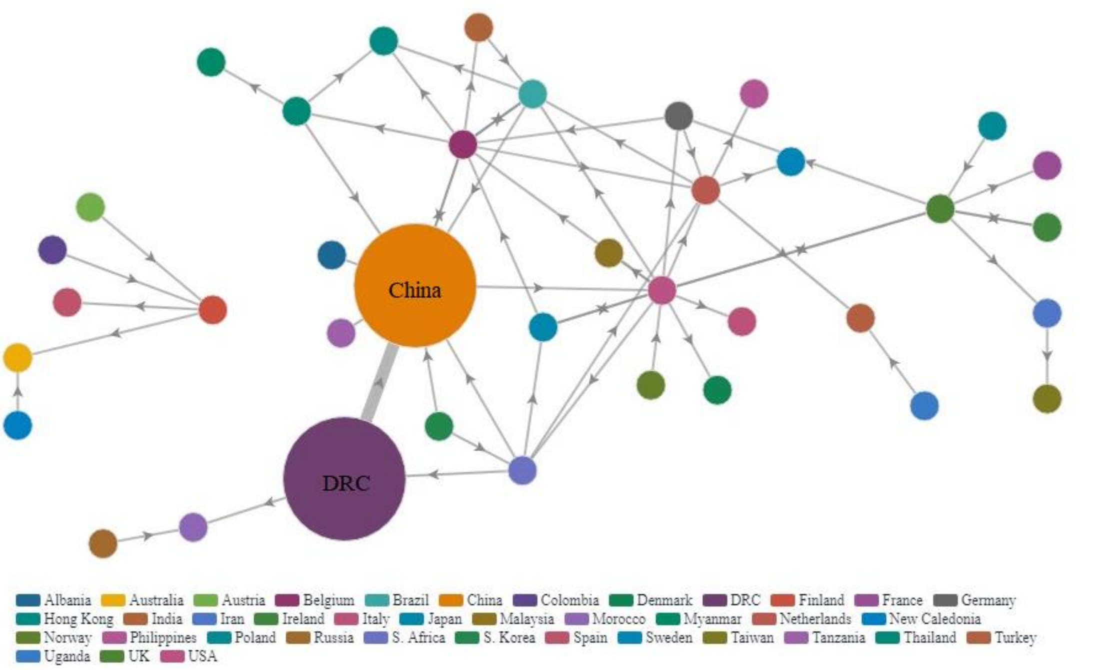
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	54	51	45	50	47	44	47	43	43	40	39
No. of links (L)	136	140	98	109	117	103	91	80	81	67	94
Density (D)	10%	11%	10%	9%	11%	11%	8%	9%	9%	9%	13%

Source: Global Trade Tracker, HS Code 260500

The data for 2017 has been presented visually in Figure 24. The importance of the two central nodes evident, as are their positions in the network. There are only two links originating from the DRC node representing exports to China and Morocco. China has links with ten other nodes.

Figure 24: Cobalt ores and concentrates ITN, 2017

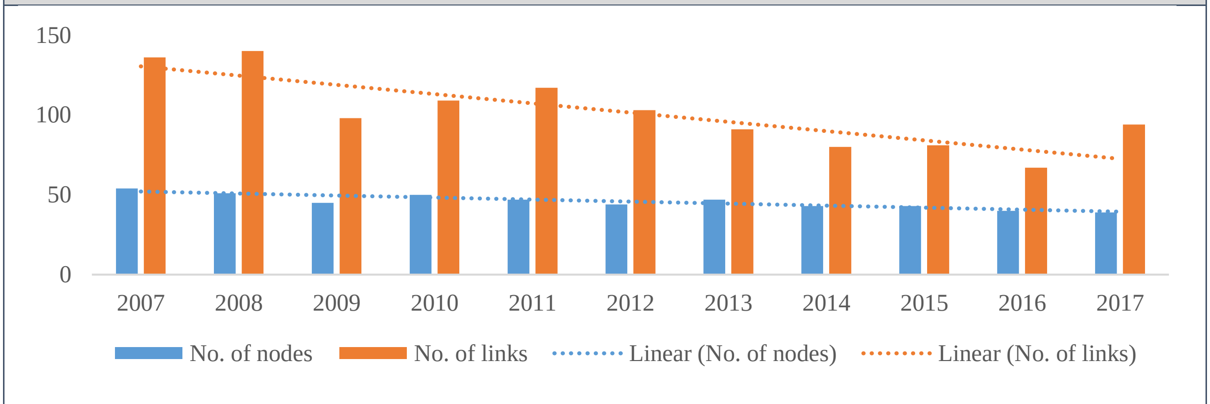
The figure shows all nodes in the cobalt ores and concentrates ITN in 2017. The size of the bubbles (nodes) and the size of the links (the lines between nodes) are determined by the scale of total exports and imports. While there are 39 nodes in total, by far the largest are China and the DRC. The link between them (exports from the DRC to China) is the most significant in the network.



Source: Global Trade Tracker, HS Code 260500

Looking at the number of nodes, or exporting/importing countries, there is some variation over the period of analysis (for which the mean number of nodes is 46). Nonetheless, a broadly flat trend is evident as shown in Figure 25. As such, there is no visible increase or reduction of the geographical scope of the chain over the period of analysis based on the number of nodes participating in it. There is considerable variation between the number of links, or instances of international trade between countries, for which the mean is 101. Over time, a decreasing trend is observed. There is no clear trend with regard to network density, which fluctuates year-on-year and averages 10%.

Figure 25: Cobalt ores and concentrates ITN summary statistics



Source: Table 17

While on average 46 countries engage in cobalt ores and concentrates trade in any given year, a high production of that trade, measured in the weight of the links between nodes, is between a far smaller number of countries as shown in Table 18.

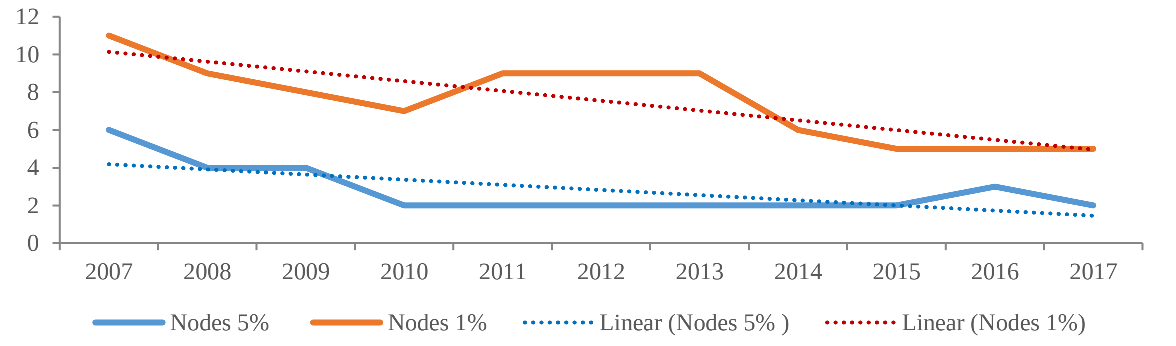
Table 18: Cobalt ores and concentrates ITN: Nodes and links

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	54	51	45	50	47	44	47	43	43	40	39
(N) >5% of trade	6	4	4	2	2	2	2	2	2	3	2
(N) >1% of trade	11	9	8	7	9	9	9	6	5	5	5
No. of links (L)	136	140	98	109	117	103	91	80	81	67	94
(L) >5% of trade	4	3	2	1	1	1	1	1	1	2	1
(L) >1% of trade	11	8	7	5	5	6	6	3	2	4	3

Source: Global Trade Tracker, HS Code 260500

When only the most significant nodes are considered, a more obvious decreasing trend is observed (Figure 26). The number of countries accounting for more than 5% of global imports/exports in any one year shows a downward trend over time. Similarly, the number of nodes representing more than 1% of annual imports/exports shows a downward trend. Thus, while there is no significant reduction in the spatial scope of the whole network, there is an apparent decrease in the number of significant nodes over time.

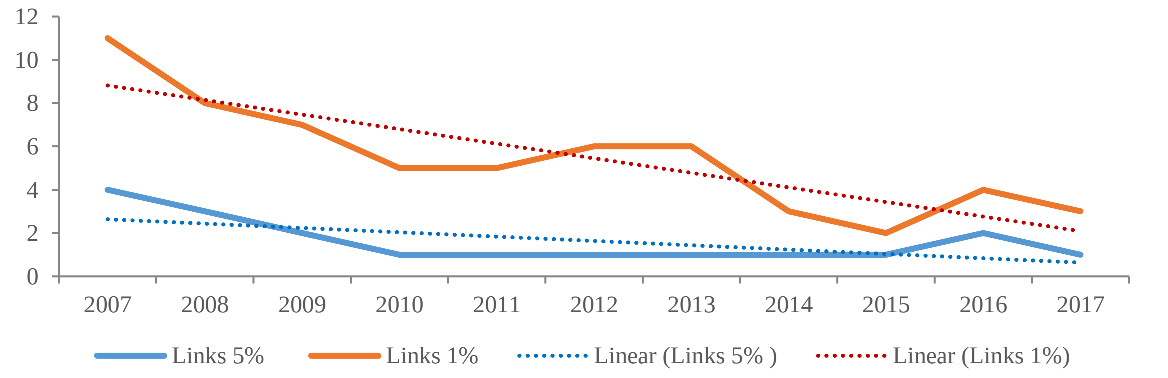
Figure 26: Cobalt ores and concentrates ITN: Nodes



Source: Table 18

As noted above, there is a decreasing trend with regard to the number of links per year during the period under analysis. Figure 27 shows that the number of links accounting for 5% and 1% of global trade also reduces over time. As such, an increasing amount of trade in the cobalt ores and concentrates ITN is conducted between a small number of nodes.

Figure 27: Cobalt ores and concentrates ITN: Links



Source: Table 18

The node in-strength of China, the world's biggest importer, increased from 72% in 2007 to 96% in 2017. Over this period, its number of trade partners, or links, decreased from 18 to 10. Put another way, by 2017 Chinese imports of cobalt ores and concentrates represented 96% of all imports globally and these imports were from just ten sources. Meanwhile, there was also an increase in the node out-strength of the DRC (from 61% in 2007 to 96% in 2017), together with decreasing trend in the DRC's number of trade partners (from six to two) and thus a drop in out-degree centrality.

Critically, Sino-DRC trade amounted to 45% of global cobalt ores and concentrates trade in 2007 but increased to 99% by 2017. This points to a high level of geographical reduction in the scope of the cobalt chain over time when trade volumes are taken into account. What can, therefore, be seen over the period of analysis, is a growing reduction in the overall importance of the wider network compared to the bilateral trade relationship between two key nodes.

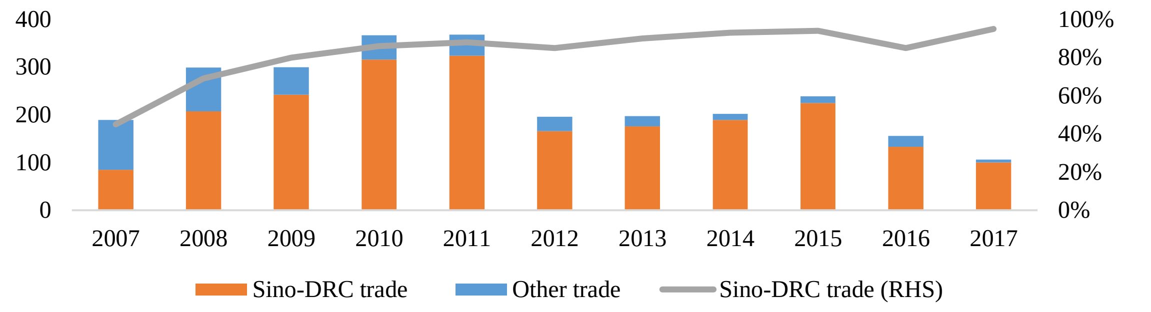
Table 19: Cobalt ores and concentrates ITN: Biggest importer (China) and exporter (DRC)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biggest importer (China)											
No. of links (L)	18	18	16	17	15	15	12	10	9	10	10
In-degree (Deg-in)	46%	44%	48%	53%	45%	43%	34%	34%	35%	42%	38%
N-in strength	72%	85%	92%	94%	94%	92%	95%	95%	96%	97%	96%
Biggest exporter (DRC)											
No. of links (L)	6	5	5	6	6	2	3	1	3	3	2
Out-degree (Deg-out)	14%	13%	17%	17%	21%	7%	9%	3%	10%	12%	7%
N-out strength	61%	76%	84%	88%	88%	85%	90%	93%	94%	85%	96%
World trade (kt)	189	299	300	367	368	196	197	202	239	156	106
Sino-DRC trade (kt)	85	207	242	316	324	166	176	189	225	133	100
Sino-DRC trade (%)	45%	69%	80%	86%	88%	85%	90%	93%	94%	85%	95%

Source: Global Trade Tracker, HS Code 260500

Figure 28 highlights the growing importance of Sino-DRC trade over the 2007 to 2017 period.

Figure 28: Sino-DRC trade vs ROW trade of cobalt ores and concentrates (kt, gross weight)



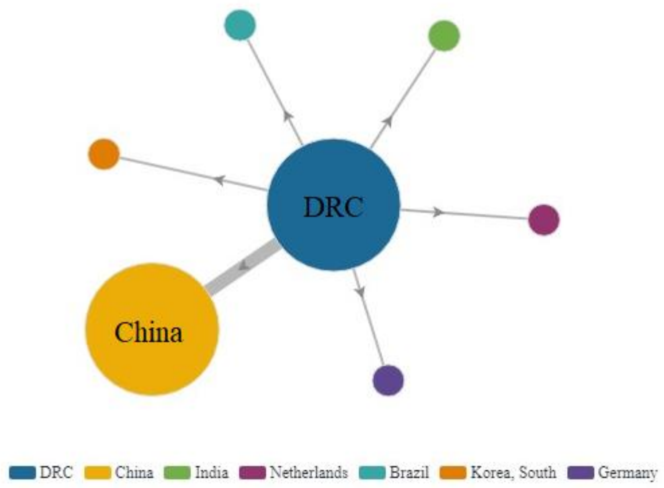
Source: Table 19

6.2 How has the cobalt intermediates ITN changed over time?

Compared to the ITN for ores and concentrates, the ITN for cobalt intermediates set out below is smaller. This is because only exports of cobalt intermediates from the DRC are visible in available trade data. Other intermediate products, those contained in nickel mattes, for example, do enter international trade, but are classified under different HS codes and are indistinguishable from nickel mattes that do not contain cobalt in trade data. As such, it is not possible to track the flows of these cobalt units for the purposes of this research. The data for 2017 has been presented visually in Figure 29, which serves to highlight the import/export relationship between two key nodes, the DRC and China.

Figure 29: Cobalt intermediates ITN, 2017

The figure shows all nodes in the cobalt intermediates ITN in 2017. The size of the bubbles (nodes) and the size of the links (the lines between nodes) are determined by the scale of total exports and imports. While there are 7 nodes in total, by far the largest are China and the DRC. The link between them (exports from the DRC to China) is the most significant in the network.



Source: Global Trade Tracker, HS Code 810520

Table 20 summarises the trade relations of all cobalt intermediates importing and exporting countries over the 2007 to 2017 period.

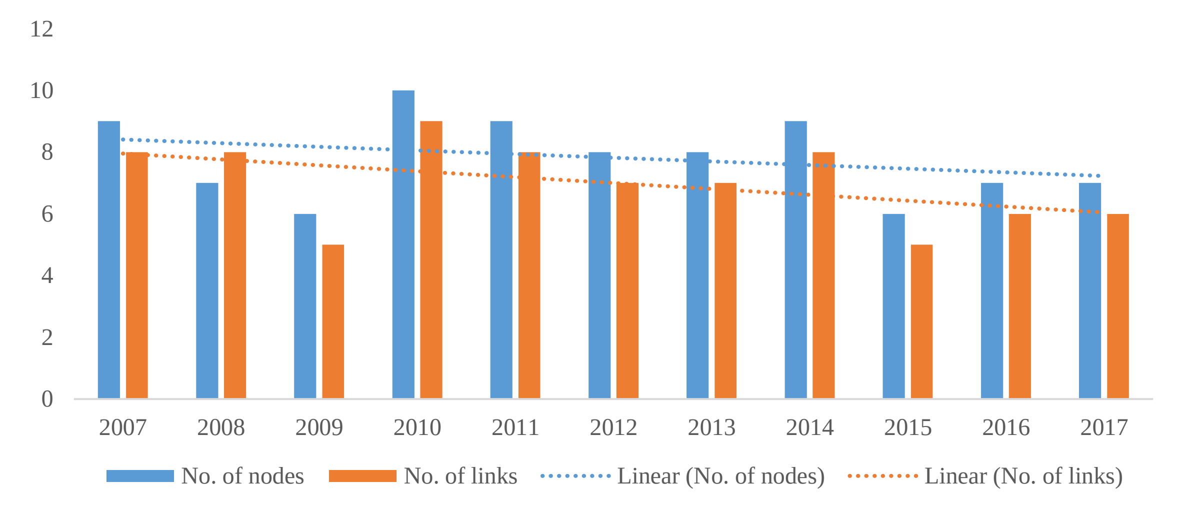
Table 20: Cobalt intermediates ITN summary statistics

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	9	7	6	10	9	8	8	9	6	7	7
No. of links (L)	8	8	5	9	8	7	7	8	5	6	6
Density (D)	22%	22%	33%	20%	22%	25%	25%	22%	33%	29%	29%

Source: Global Trade Tracker, HS Code 810520

There is some variation in the number of nodes engaged in the ITN over the period of analysis (for which the mean number of nodes is 8) with a marginal downward trend as shown in Figure 25. There is also some variation in the number of links, or instances of international trade between countries, over this period, for which the mean is 7. Again, over time a modest downward trend is observed. Network density averages 26%. As such, there is evidence of only a marginal reduction of the geographical scope of the chain over the period of analysis.

Figure 30: Cobalt intermediates ITN summary statistics



Source: Table 20

As is the case with analysis of the cobalt ores and concentrates ITN, the picture becomes different when the weight of the links between nodes is factored in. While on average eight countries engage in cobalt intermediates trade in any given year, a high production of that trade, measured in the weight of the links between nodes, is between a small number of countries.

Table 21: Cobalt intermediates ITN: Trade volumes of nodes and links

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	9	7	6	10	9	8	8	9	6	7	7
(N) >5% of trade	3	3	3	3	3	3	3	3	2	2	2
(N) >1% of trade	3	4	4	4	3	3	3	3	2	2	2
No. of links (L)	8	8	5	9	8	7	7	8	5	6	6
(L) >5% of trade	2	2	2	2	2	2	2	2	1	1	1
(L) >1% of trade	2	3	3	3	2	2	2	2	1	1	1

Source: Global Trade Tracker, HS Code 810520

As was the case with the cobalt ores and concentrates ITN, it is Sino-Congolese trade that has come to dominate the ITN for cobalt intermediates. In 2007, Chinese imports represented 19% of global imports. By 2017, Chinese imports, as measured by N-in strength, accounted for >99% of the global total. An important fact to note is the rising volume of trade over the period of analysis. This is evidence of the growing demand for cobalt intermediates as a feedstock for refined cobalt chemical and metal production, at the expense of cobalt ores and concentrates (volumes of ore and concentrate trade decreased over time as shown in Figure 22 and Figure 23). Increased trade is underpinned almost exclusively by trade between the DRC and China.

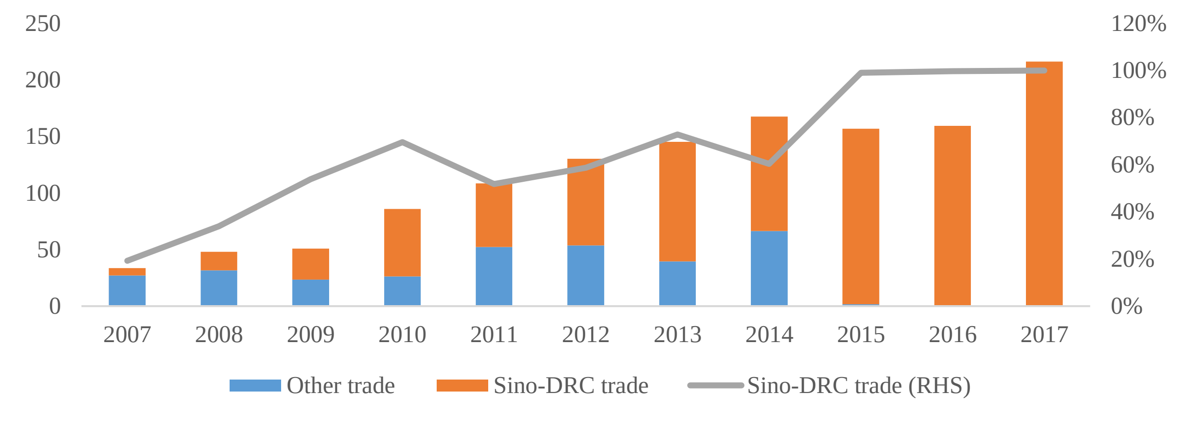
Table 22: Cobalt intermediates ITN: Biggest importer (China)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biggest importer (China)											
No. of links (L)	1	1	1	1	1	1	1	1	1	1	1
In-degree (Deg-in)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N-in strength	19%	34%	54%	70%	52%	59%	73%	60%	99%	100%	100%
World trade (kt)	33.7	48.0	50.8	85.8	108.3	130.1	145.2	167.3	156.6	159.1	216.1
Sino-DRC trade (kt)	6.48	16.25	27.33	59.62	56.04	76.31	105.59	100.97	154.78	158.45	215.75
Sino-DRC trade (%)	19%	34%	54%	70%	52%	59%	73%	60%	99%	100%	100%

Source: Global Trade Tracker, HS Code 810520

Figure 31 shows the growing importance of Sino-Congolese trade over the 2007 to 2017 period.

Figure 31: Sino-DRC trade vs world trade of cobalt intermediates (kt, gross weight)



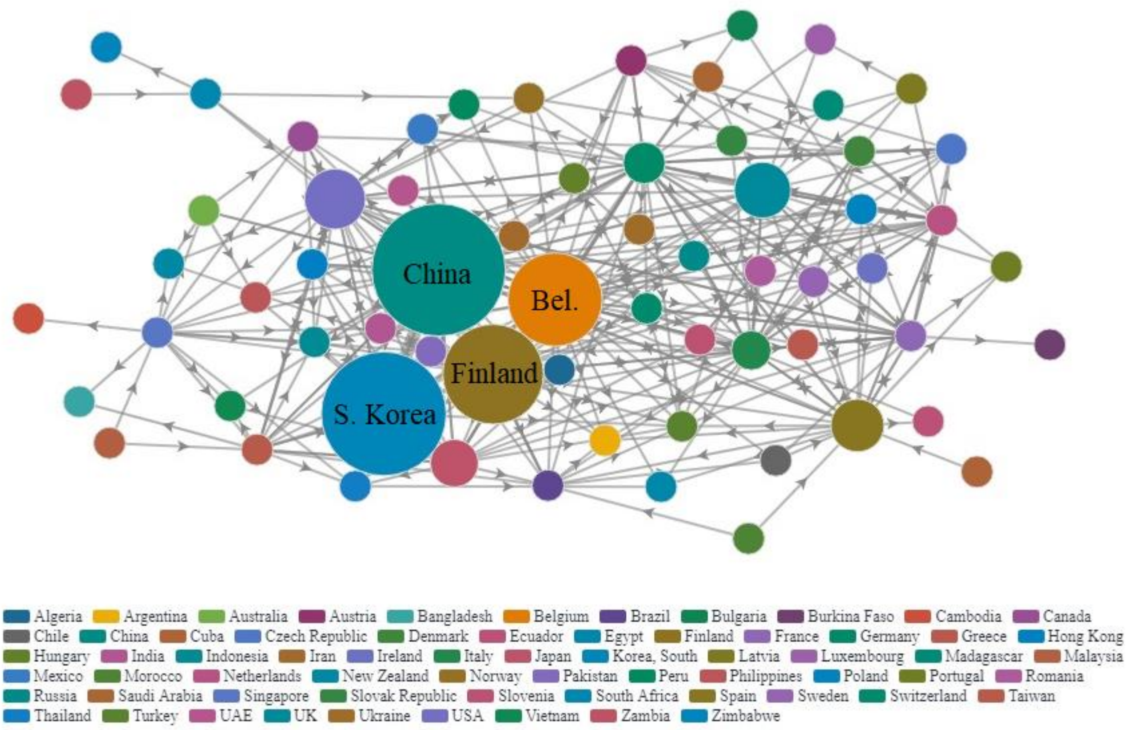
Source: Table 22

6.3 How has the refined cobalt chemicals ITN changed over time?

Rather than essentially being industrial raw materials like cobalt ores and concentrates and intermediates, cobalt chemicals are used in the production of final products such as automotive batteries and pigments. For this reason, the number of nodes engaged in the ITN is much larger than is the case for ores and concentrates and intermediates, reflecting the wider consumption base of cobalt chemicals across multiple jurisdictions. The ITN for 2017 is shown in Figure 29. It shows how four key nodes dominate the network.

Figure 32: Cobalt chemicals ITN, 2017

The figure shows all nodes in the cobalt chemicals ITN in 2017. The size of the bubbles (nodes) and the size of the links (the lines between nodes) are determined by the scale of total exports and imports. While there are 70 nodes in total, the largest are China, South Korea, Finland and Belgium.



Source: Global Trade Tracker, HS Codes 282200, 282734 and 291523

Table 26 summarises the trade relations of all refined cobalt chemicals importing and exporting countries over the 2007 to 2017 period.

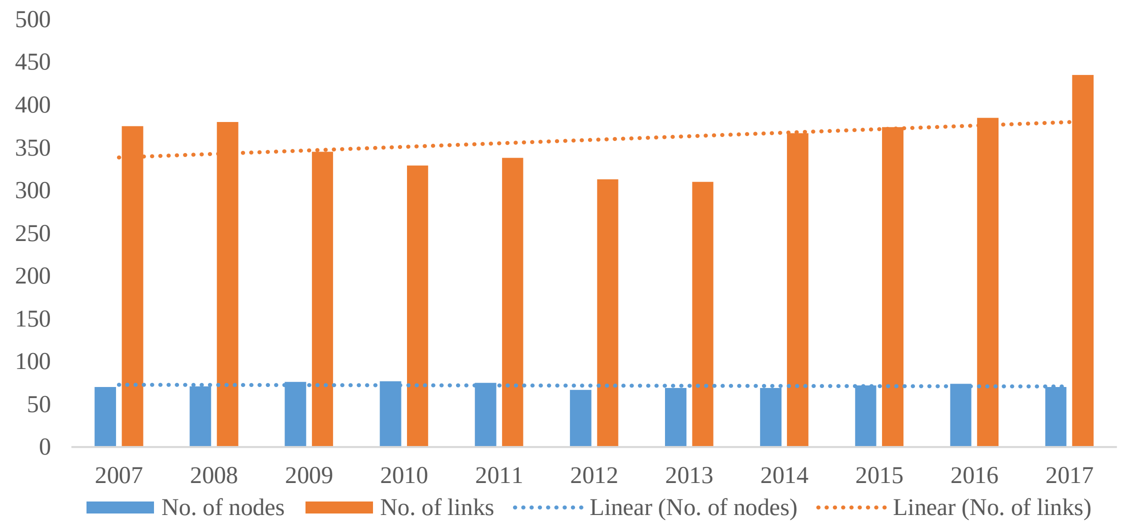
Table 23: Refined cobalt chemicals ITN summary statistics

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	70	71	76	77	75	67	69	69	72	74	70
No. of links (L)	375	380	345	329	338	313	310	367	374	385	435
Density (D)	16%	15%	12%	11%	12%	14%	13%	16%	15%	14%	18%

Source: Global Trade Tracker, HS Codes 282200, 282734 and 291523

The number of nodes engaged in the ITN remains relatively consistent over time. The number of links shows a slight upwards trend, as does network density.

Figure 33: Refined cobalt chemicals ITN summary statistics



Source: Table 23

While the number of nodes engaged in the ITN is higher than in the preceding examples, it remains that case that only a small number of nodes and links reflect a significant share of all trade in any given year. The average number of links was 359, whereas only an average of 21 accounted for more than 1% of global trade in any given year, suggesting that the vast majority of exchanges between nodes are of relatively small quantities of refined cobalt chemicals.

Table 24: Refined cobalt chemicals ITN: Nodes and links

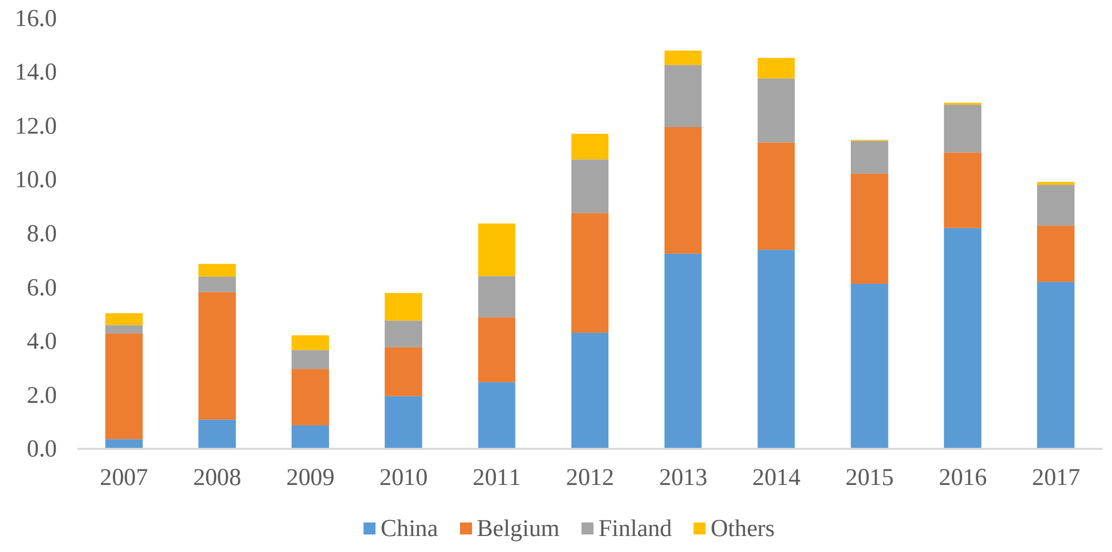
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	70	71	76	77	75	67	69	69	72	74	70
(N) >5% of trade	11	12	11	11	8	9	8	8	8	8	7
(N) >1% of trade	30	27	25	25	22	21	21	22	20	20	22
No. of links (L)	375	380	345	329	338	313	310	367	374	385	435
(L) >5% of trade	1	2	4	3	5	4	4	3	3	4	4
(L) >1% of trade	25	20	23	26	22	21	16	18	18	18	20

Source: Global Trade Tracker, HS Codes 282200, 282734 and 291523

Three countries, Belgium, China and Finland, have been the key exporting nodes in the ITN over the period of analysis. South Korea is the main importing node. Each of the three exporters had high out-degree centrality in any given year reflecting engagement with a large proportion of importing nodes. China's share of global exports, as measured by n-out strength, increased significantly over the period of analysis.

South Korea was by far the most significant importing node over the period under analysis. Its node-in strength, that is its share of world imports, shows a broadly upwards trend. Node in strength exhibits an upward trend also. South Korea's growing dependence on the three biggest exporting nodes is shown in Figure 34. Once again, the growing importance of China is evident.

Figure 34: South Korean imports of refined cobalt chemicals (kt, gross weight)



Source: Table 25

Table 25: Refined cobalt chemicals ITN: Biggest importer and exporters

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Exporter (China)											
No. of links (L)	41	44	31	40	35	34	34	34	36	35	30
Out-degree (Deg-out)	0.63	0.69	0.52	0.65	0.57	0.57	0.57	0.57	0.59	0.52	0.48
N-out strength	19%	20%	11%	21%	20%	24%	35%	35%	36%	38%	34%
Exporter (Belgium)											
No. of links (L)	32	30	29	32	30	36	32	33	37	33	33
Out-degree (Deg-out)	0.49	0.47	0.48	0.52	0.49	0.60	0.53	0.55	0.61	0.49	0.52
N-out strength	33%	35%	30%	25%	28%	29%	27%	24%	32%	25%	21%
Exporter (Finland)											
No. of links (L)	35	36	32	31	34	31	27	30	29	30	26
Out-degree (Deg-out)	0.54	0.56	0.53	0.50	0.56	0.52	0.45	0.50	0.48	0.45	0.41
N-out strength	13%	12%	21%	21%	21%	17%	19%	18%	17%	20%	27%
Importer (S. Korea)											
No. of links (L)	12	13	13	12	12	10	11	12	9	13	14
In-degree (Deg-in)	0.41	0.42	0.36	0.36	0.40	0.33	0.39	0.41	0.29	0.35	0.36
N-in strength	28%	35%	32%	35%	43%	47%	54%	53%	52%	50%	39%
Trade volume (kt)	18.3	19.8	13.1	16.8	19.4	25.1	27.3	27.4	21.9	25.9	25.2
S. Korea imports (kt)	5.0	6.9	4.2	5.8	8.4	11.7	14.8	14.5	11.5	12.9	9.9
S. Korea imports from China, Belgium & Finland	91%	93%	87%	82%	77%	92%	96%	95%	100%	100%	99%

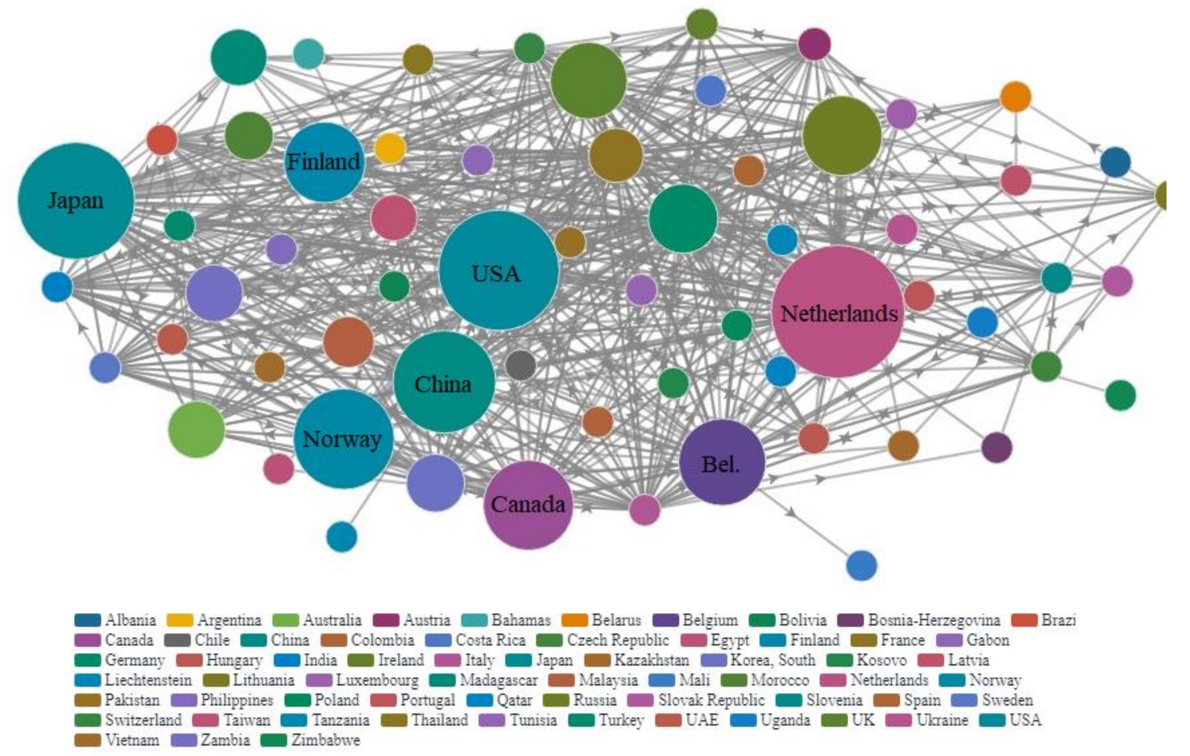
Source: Global Trade Tracker, HS Codes 282200, 282734 and 291523

6.4 How has the refined cobalt metal ITN changed over time?

Cobalt metal is traded by physical commodity traders, producers and consumers, and is tradeable on the London Metals Exchange. Further, cobalt metal is consumed in a wide variety of end-use applications such as in automobiles, aircraft and magnets and thus the trade network is large given the widespread manufacture of these products across multiple geographies. The ITN for 2017 is shown in Figure 29.

Figure 35: Cobalt metals ITN, 2017

The figure shows all nodes in the cobalt chemicals ITN in 2017. The size of the bubbles (nodes) and the size of the links (the lines between nodes) are determined by the scale of total exports and imports. While there are 63 nodes in total, the largest are Netherlands, USA, Japan, China, Norway, Finland, Canada and Belgium.



Source: Global Trade Tracker, HS Codes 810510, 810520 and 810590

Table 26 summarises the trade relations of all refined cobalt metals importing and exporting countries over the 2007 to 2017 period.

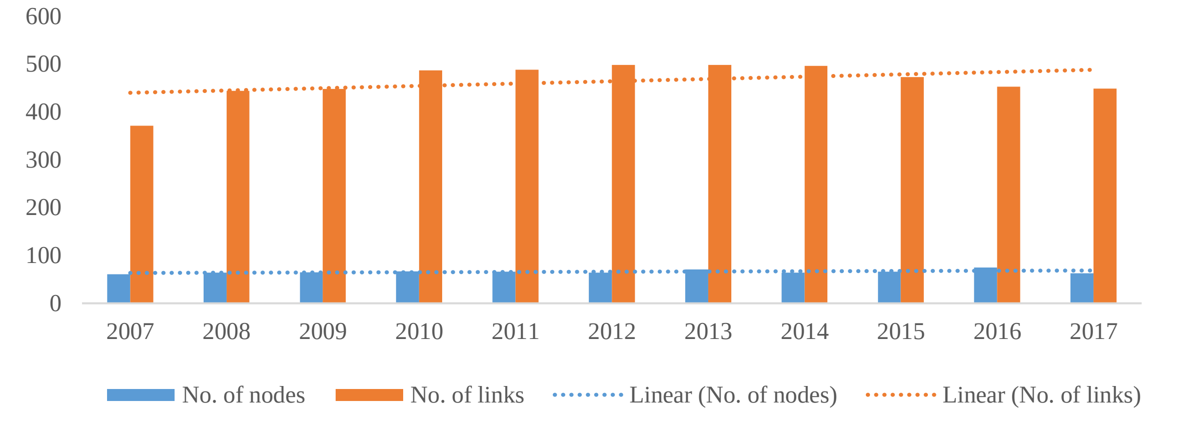
Table 26: Refined cobalt metal ITN summary statistics

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	61	64	65	67	66	64	71	64	66	75	63
No. of links (L)	371	444	448	487	488	498	498	496	473	453	449
Density (D)	20%	22%	22%	22%	23%	25%	20%	25%	22%	16%	23%

Source: Global Trade Tracker, HS Codes 810510, 810520 and 810590

A broadly upward trend is visible with regard to the number of nodes and links. On average, 66 nodes were engaged in refined cobalt trade in any one year.

Figure 36: Refined cobalt metal ITN summary statistics



Source: Table 26

A high proportion of trade, measured in the weight of the links between nodes, is between a small number of countries as shown below. On average, 14 nodes imported or exported more than 5% of the total volume of material traded in any one year.

Table 27: Refined cobalt metal ITN: Nodes and links

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of nodes (N)	61	64	65	67	66	64	71	64	66	75	63
(N) >5% of trade	13	13	12	13	13	14	14	15	16	14	13
(N) >1% of trade	29	33	32	31	34	34	33	31	31	32	31
No. of links (L)	371	444	448	487	488	498	498	496	473	453	449
(L) >5% of trade	3	1	2	2	2	1	2	2	1	3	3
(L) >1% of trade	26	22	21	26	27	27	26	30	29	24	24

Source: Global Trade Tracker, HS Codes 810510, 810520 and 810590

Canada and Finland were the key exporting nodes over the period of analysis. Japan, the USA and China were the principal importing nodes. As is the case with cobalt ores and concentrates and intermediates, China's growing importance as an importer is evident through the upward trend in node in-strength and number of links.

Table 28: Refined cobalt metal ITN: Biggest importer and exporters

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Exporter (Canada)											
No. of links (L)	22	21	21	25	25	24	26	23	26	24	23
Out-degree (Deg-out)	0.43	0.41	0.38	0.49	0.45	0.44	0.45	0.42	0.47	0.39	0.40
N-out strength	15%	13%	13%	10%	10%	14%	13%	11%	13%	14%	11%
Exporter (Finland)											
No. of links (L)	25	21	26	21	23	21	21	20	20	18	19
Out-degree (Deg-out)	0.49	0.41	0.47	0.41	0.42	0.38	0.36	0.36	0.36	0.30	0.33
N-out strength	13%	11%	10%	10%	10%	11%	9%	11%	10%	7%	9%
Importer (Japan)											
No. of links (L)	17	17	18	20	16	18	16	16	15	26	24
In-degree (Deg-in)	0.47	0.41	0.43	0.43	0.34	0.40	0.33	0.36	0.33	0.58	0.52
N-in strength	28%	26%	23%	22%	19%	18%	16%	17%	16%	12%	15%
Importer (USA)											
No. of links (L)	17	20	19	22	19	23	22	20	21	31	32
In-degree (Deg-in)	0.47	0.49	0.45	0.47	0.40	0.51	0.46	0.45	0.46	0.69	0.70
N-in strength	20%	15%	14%	15%	14%	17%	16%	18%	18%	19%	16%
Importer (China)											
No. of links (L)	9	16	20	19	18	18	21	19	20	28	28
In-degree (Deg-in)	0.25	0.39	0.48	0.40	0.38	0.40	0.44	0.43	0.43	0.62	0.61
N-in strength	4%	5%	17%	15%	15%	12%	19%	15%	14%	11%	10%

Source: Global Trade Tracker, HS Codes 810510, 810520 and 810590

6.5 Summary

The previous chapter showed that the production and consumption of cobalt grew substantially over the decade to 2017. This chapter has shown that the growth in cobalt demand and supply brought about not only an increase in international trade volumes but also a reconfiguration of the cobalt trade network.

Four ITNs for cobalt were analysed. The size of the four ITNs outlined above, as measured by the number of nodes and links, didn't change significantly over time. However, several important stylised facts were unearthed about the ITNs, and in particular, the analysis illuminates the increasing importance of certain exporting and importing nodes within these networks.

Analysis of the cobalt ores and concentrates ITN showed no particular reduction in the size of the network as measured by the number of nodes operating within it, despite the fact that in volume terms trade reduced over time. A decreasing trend in the number of links or instances of trade was observed. The most important observation was that the number of nodes and links accounting for >5% and >1% of global imports/exports in any one year showed a downward trend over time. Critically, the analysis highlighted the emergence of China and the DRC as the world's dominant importing and exporting nodes respectively. Trade between these two nodes increased over time and by 2017, Sino-Congolese trade represented 95% of all trade in the cobalt ores and concentrates ITN.

Analysis of the cobalt intermediates ITN also served to highlight the growing importance of bilateral trade relations between the DRC and China within the trade network. Trade between these two nodes increased over time and by 2017, Sino-Congolese trade represented 100% of all trade in the ITN.

Analysis of the downstream part of the cobalt chain, that is the refined cobalt chemicals ITN and the refined cobalt metals ITN, has shown that despite the dominance of China and the DRC further upstream, there are numerous other important nodes elsewhere in the network. The analysis also served to highlight that these networks are far larger than the upstream ITNs as measured by the number of active nodes and links.

In the refined cobalt chemicals ITN, while the number of nodes engaged in the ITN is higher than in the preceding examples, it remained that case that only a small number of nodes and links reflect a significant share of all trade in any given year. The analysis showed how most exports in the ITN were from three exporting nodes: China, Belgium and Finland. The combined N-out strength of these three nodes averaged 73% over the period under analysis and showed an upward trend over time.

Analysis of the refined cobalt metal ITN provides several interesting findings. Not only did the overall volume of trade increase over time, but there was also an increase in the geographic scope of the network. Much of this trade has been between countries importing and exporting relatively small quantities of metal. As with all of the other cobalt ITNs, a high proportion of trade was between a small number of nodes.

When all four cobalt ITNs are considered, the cobalt network appears to fit well with the traditional core-periphery model. Raw materials are produced and exported from nodes in the periphery, most notably the DRC, to nodes in the core (such as China, South Korea, and the USA) and consumed in the manufacture of higher-value cobalt-bearing products.

This chapter was designed to explore RQ2 which asked: How has the spatial structure of the cobalt sector changed over time? Given cobalt's territorial embeddedness in certain states, it was not expected that the geographies of the sector would have changed radically as, at the upstream part of the supply chain at least, only certain states (those who produce cobalt raw materials) can serve as exporters. It was expected, however, that countries without cobalt resources would have sought to ensure access to cobalt units by diversifying their supply chains and increasing their imports. The following hypothesis was put forward:

The geographies of cobalt trade will have altered over time yet retain their core-periphery basis defined, in part, by geology.

The preceding analysis serves to confirm this hypothesis to some extent. Certainly, the analysis above suggests that trade volumes have been somewhat volatile over time and that various bilateral trade relationships within the various ITNs have changed over time.

Chapter 6.1 and Chapter 6.2 confirmed that the geographies of the sector remained broadly similar, as measured by key tools such as network density, with one key exporting node (the DRC) as a central actor. However, these chapters also served to highlight how increasingly over time, a high production of that trade, measured in the weight of the links between nodes, was between a small number of countries. In particular, the emerging dominance of Sino-Congolese bilateral trade was evident.

Despite being altogether different types of trade networks (as the goods traded are refined products whose geographies are not necessarily so impacted by geology), Chapter 6.3, and Chapter 6.4 also showed how, over time, the strength of certain trade relationships intensified.

Additional discussion of the findings of this chapter and the viability of using an ITN approach in this context can be found in the conclusion.

***

The application of a GPN approach to the cobalt sector, to show its structure and organisation, and the application of an ITN approach to cobalt trade, to show changing interdependencies between states, are useful approaches for the presentation of 'outcomes' in the cobalt supply chain. However, these descriptive tools can only tell us so much about a supply chain. While the approaches taken has proved to be illuminating, they have little explanatory power.

Contemporary organisational structures and patterns of trade are the outcomes of various network interactions, shaped by a wide number of actors, market forces and dynamics. Part III is concerned with exploring what these dynamics are, and how various actors have responded to them.

Part III

Part II of this dissertation was concerned with observed outcomes in the cobalt sector. Part III focusses on exploring the causal mechanisms that have shaped these outcomes. Contemporary organisational structures and patterns of trade are the outcomes of various network interactions, shaped by a wide number of actors, market forces and dynamics. The following two chapters examine some of these dynamics, and how various actors have responded to them, making use of case studies and the findings of desk-based research, a cobalt-sector survey, and semi-structured interviews.

Chapter 7 addresses RQ3: how have firms responded to perceived resource scarcity and demand growth? It, thus, examines firm behaviours and responses to cobalt's criticality. Specifically, the chapter explores two hypotheses set out in Part I (chapter 3.5) and derived from the literature review. The first is that in response to cobalt's criticality, firms would have engaged in foreign direct investment (FDI) and resource-seeking. The second is that because of cobalt's criticality, firms would have vertically integrated both forwards and backwards in order to strengthen their position in the supply chain.

Chapter 8 turns attention on the response of states to cobalt's criticality and addresses RQ4: how have states responded to perceived resource scarcity and demand growth? It, too, tests hypotheses, set out in Part I (chapter 3.5), that resource-holding states will have undertaken resource nationalist approaches in order to capture value from the cobalt sector, while resource-seeking states will have created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value. This chapter explores RQ4 and these two hypotheses through a focus on two case-study states, one resource-holding and one resource-seeking. The DRC is selected as the former, given that it has by far the world's largest cobalt reserves and resources, and is the largest mine producer of cobalt globally (USGS, 2016c). China is selected as the case study resource-seeking state as it is by far the world's biggest importer of unrefined cobalt and producer of refined cobalt.

Figure 37 provides an overview of the structure of the thesis. The relevant chapters and research questions for Part III are highlighted in red.

Figure 37: Dissertation structure

Part	Part I - Research background				Part II - Outcomes in the cobalt sector		Part III - Responses in the cobalt sector		Part IV - Discussions and conclusions
Summary	Part I introduces the reader to the debates surrounding resource scarcity and critical materials and the cobalt sector. It then reviews the literature relevant to the research				Part II examines outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time		Part III is concerned with identifying some of the causal mechanisms that have shaped the observed outcomes detailed in Part II. It explores how cobalt's criticality has shaped the behaviours of firms and states		Part IV contains the research's conclusions
Chapter	C1. Introduction	C2. Resource scarcity, critical materials and the case of cobalt	C3. Theoretical debates on the nature and organisation of global supply chains	C4. Methodology	C5. A GPN approach to examining how the cobalt supply chain is structured and organised	C6. An ITN approach to charting the reconfiguration of the cobalt supply chain	C7. Firm responses to cobalt's criticality	C8. State responses to cobalt's criticality	C9. Conclusions and discussion
Summary	Introduces the research and outlines its background aims, key questions and structure	Introduces key literature on resource scarcity and critical materials before selecting a case study raw material (cobalt)	Introduces theories of international trade, theories of the firm and theories of global chains and networks relevant to the research	Discusses the use of GPN and ITN approaches for Part II and the use of case studies, a survey and semi-structured interviews for Part III	Uses a Global Production Network approach to show how the cobalt supply chain is structured and coordinated	Uses an International Trade Network approach to show how the geographies of the cobalt chain have evolved over time	Focussing on the upstream part of the sector in the DRC, the chapter looks at how firms have responded to cobalt's criticality exploring FDI and integration in particular	Focussing on the cobalt sector's major resource-holding state (the DRC) and resource-seeking state (China) this chapter explores how states have responded to cobalt's criticality	This chapter outlines key research conclusions, discusses the implications of the research findings, and outlines areas for additional study
Research questions addressed					RQ1: How is the cobalt supply chain structured and coordinated?	RQ2: How has the spatial structure of the cobalt sector changed over time?	RQ3: How have firms responded to supply risk and economic importance?	RQ4: How have states responded to supply risk and economic importance?	

Note: Red lines denote the current part

7. Firm responses to cobalt's criticality

In this chapter, RQ3 is explored which asks: How have firms responded to perceived resource scarcity and demand growth? As set out in Part I (chapter 3.5), the review of the literature led to the generation of two hypotheses which this chapter examines. The first was that firms would have engaged in foreign direct investment (FDI) and resource-seeking in response to cobalt's criticality. The second was that because of cobalt's criticality, firms would have vertically integrated both forwards and backwards in order to strengthen their position in the supply chain.

Based on the findings of the cobalt-sector survey and insights from semi-structured interviews, this chapter will explore these two areas in depth. First, FDI in the cobalt sector will be examined. The sub-chapter begins with a historical analysis of firms operating in the DRC. This contextual analysis is followed by a presentation of findings from Part B of the cobalt-sector survey, which gathered market participants' opinions on FDI in the cobalt sector, alongside a discussion of these findings which makes use of some insights gleaned from interviews.

Thereafter, integration in the cobalt supply chain is considered. The sub-chapter commences with a short case study of Huayou Cobalt, the world's largest producer of refined cobalt. The case study shows that at its inception, Huayou Cobalt was engaged in only one stage of the cobalt supply chain but that over time it has integrated backwards and forwards. After this illustrative example is set out, the sub-chapter considers the findings from Part C of the cobalt-sector survey, which gathered market participants' opinions on integration in the cobalt sector, alongside the findings of semi-structured interviews.

7.1 Foreign direct investment in the cobalt sector

A key hypothesis set out in Part I was that in response to cobalt's criticality, firms would engage in foreign direct investment (FDI) and resource-seeking (where firms seek to acquire resources that are not available domestically). Before examining this issue in light of the findings of both the cobalt-sector survey and semi-structured interviews, it is first useful to present a short history of FDI in the cobalt sector to provide historical context.

To do so, this sub-chapter narrows the focus onto the upstream part of the sector, looking specifically at firms engaged in cobalt mining in the DRC, the world's main source of cobalt. Using historical reports on the cobalt sector from several sources, the following sub-chapter charts the evolution of cobalt extraction from colonial times, when cobalt extraction was exclusively in the hands of one company, to the present day, where the sector in the DRC is characterised by high levels of FDI and public-private partnerships.

7.1.1 A history of cobalt firms in the DRC

Over the past two decades, Congo's copper and cobalt industry has transitioned from a fully state-owned sector to a patchwork of private operations with Chinese, Swiss, American, Kazakh, and other Investors.

Carter Centre, 2017

7.1.1.1 A nationalised cobalt and copper sector (1924 to 1994)

Securing access to the raw material riches of Africa was one of the main preoccupations of European powers in the nineteenth century. In 1879, The International Association of the Congo was founded, bringing the Congo basin under the control of Leopold II of Belgium. Following the 1884 Berlin Conference, which sought to regulate and legitimise European colonisation in the Central African region, the *État Indépendant du Congo* (Congo Free State) was formed in 1885. Congo Free State was, in effect, governed by absolute monarchy by Leopold II.

The Government of Belgium took control of the Congo Free State in 1908, a year before the death of Leopold II. It became a Belgian colony, Belgian Congo, in 1909. At this time, mineral exploration in the region was undertaken solely by the Belgian company, *Union Minière du Haut Katanga* (UMHK). UMHK was set up in 1906 and formed to exploit mineral deposits on behalf of Tanganyika Concessions Limited, a British company listed on the London Stock Exchange in January 1899 (Särkkä, 2016). Copper production is thought to have commenced as early as 1906, with cobalt production starting in 1924 with the introduction of new processing techniques (Kalenga, 1924). A cobalt recovery plant was installed at Panda in 1924 (Roskill, 1979) and within the space of a few years, the country became the world's primary source of cobalt.

The Belgian Congo gained independence from Belgium in 1960, becoming *République du Congo* in 1964. After several years of instability, Joseph-Désiré Mobutu seized power in a coup in 1965. Mobutu renamed the country Zaire in 1971. In 1967, UMHK was nationalised and formed into a new company, *La Générale des Carrières et des Mines du Zaire* (Gécamines). Gécamines was the sole copper and cobalt producer and soon after it inherited the deposits from its colonial predecessor, it boosted production and kept levels high for the next two decades. "This was Gécamines' *belle époque*, and the state-owned company was a symbol of status and pride." (Carter Centre, 2017, 16). However, a lack of investment in infrastructure, coupled with ongoing violence and instability in Katanga province (where secessionist conflicts had occurred in the 1970s), led to declining output.

Production of copper and cobalt began to fall drastically in the 1990s, exacerbated by the collapse of the main Kamoto underground copper mine (Kasongo, 2015). Lower output led to a decrease in tax revenues: mining, as a share of national tax revenues, averaged only 7% between 1991 and 2000, down from 60% in the 1980s (Kasongo, 2015). By the early 1990s, Gécamines and the country's copper and cobalt sectors were in terminal decline. Two waves of pillaging in 1991 and 1993 by Mobutu's angry, unpaid military forces hastened Gécamines' downfall as did 1993's ethnic violence by Katangans against people from the Kasai province, who had dominated Gécamines' senior management for years and were forced to flee the xenophobic violence (Carter Centre, 2017).

As noted by the Carter Centre (2017), when Gécamines' production collapsed, and tax revenues dwindled, the privatization of its concessions became an alternative mechanism to raise funds. Desperate for money, Mobutu's government agreed to sell off key copper-cobalt assets to boost the government coffers. Thus, privatization of the copper and cobalt belt began as a matter of necessity rather than as a policy choice (Carter Centre, 2017).

7.1.1.2 FDI in the DRC cobalt sector begins (1995 to 2001)

Initial FDI in the DRC's copper and cobalt assets was tied to civil conflict in the country. Both the government and rebel groups began using the promise of mining permits to raise finance to fund their military operations. While the Mobutu government were negotiating some initial privatisation contracts in an effort to raise finances, Laurent-Désiré Kabila's rebel army was gaining strength, eventually toppling the government in May 1997. Before the rebels took the capital, Kinshasa, they had taken Lubumbashi in April 1997. There, they held talks at the Grand Karavia hotel with investors that had signed preliminary agreements with Mobutu (Carter Centre, 2017). As a UN Expert Panel later concluded, one way of securing the engagement of some allies in the war was the provision of financial incentives by way of creating business opportunities in the mining sector (UN Security Council, 2001).

At the Grand Karavia hotel meetings, reports suggest that American investor Jean-Raymond Boulle, owner of America Mineral Fields (AMF), secured a US$1Bn contract for copper-cobalt tailings in Kolwezi, even lending Kabila his company's aeroplane to help secure the deal (Carter Centre, 2017; Economist, 1998). AMF had won a tender for the Kolwezi tailings in 1995, but, at the request of South Africa's Anglo American Corporation, the bidding was reopened (Economist, 1998). This prompted Boulle to begin negotiations with the rebels, rather than Mobutu's government, which was closer with large mining companies (Economist, 1998). While Boulle and Kabila reportedly struck a deal in 1997, the contract was cancelled in 1998.

Other firms that may have undertaken FDI of sorts over this period include Lundin Mining. Mobutu's government had selected Lundin in a tender for the Tenke and Fungurume deposits on the basis of Lundin's signing bonus offer, which was larger than that of other candidates (Carter Centre, 2017). Kabila later confirmed the preliminary agreement that Mobutu had initiated with Lundin, which, according to the Tenke Fungurume Mining Convention, generated a US$50M upfront payment. Two years later, Lundin declared *force majeure,* suspending its contractual obligations and the project then lay dormant for several years (Carter Centre, 2017).

Once Laurent-Désiré Kabila had assumed the presidency, the formal sale of Gécamines assets began. This ended a period of mining sector nationalisation which had endured since independence. Despite some protestation, those in charge of Gécamines followed presidential instructions to sign away key assets and Gécamines' former monopoly began to shrink (Carter Centre, 2017). According to Roskill data, three non-Congolese firms had entered joint-venture agreements with Gécamines regarding cobalt mine assets by 2001 (Table 29).

Early FDI in the cobalt sector was somewhat underpinned by post-colonial relationships with two of the three initial foreign companies being Belgian. The first was *Union Minière*, which traced its history back to UMHK. UMHK had continued activities when its assets in Zaire were nationalised and sought to develop new mining and refining activities elsewhere (Umicore, 2017). The Union Minière-Gécamines joint-venture was reportedly set up in 1995. The partners operated the Kasombo cobalt mine which began production in 1996 (Roskill, 2004). The second was a joint-venture, Group for the treatment of Terril Lubumbashi (GTL), set up by *Groupe George Forrest*, of Belgium, and Gécamines regarding the Luiswishi mine, hitherto part of Gécamines' South Group. Groupe George Forrest was the parent company of *Enterprise Générale Malta Forrest* (EGMF), which incorporated in 1922 in Belgian Congo and had undertaken numerous infrastructure projects in the region (EGMF, 2017). A second foreign firm, OMG of the USA, signed an agreement with Gécamines to purchase all of the concentrate produced by the Luiswishi mine and export it for processing at its plant in Finland (Roskill, 2004).

It is not possible to distinguish the domicile of the owners of Gécamines' other joint-venture partner. Kababankola Mining Company (KMC) was formed in January 2001 following the signing of a joint venture agreement between Tremalt and Gécamines (Roskill, 2004). According to a UN document, Tremalt had the rights to exploit six Gécamines concessions containing 325kt of cobalt over 25 years, paying the Government US$400,000 although the estimated worth of the concessions was US$1Bn (UN

Security Council, 2002). The ultimate owners and beneficiaries of Tremalt were reportedly hidden behind a web of trusts and private holding companies registered in the British Virgin Islands and the Isle of Man (UN Security Council, 2002).

Table 29: FDI in DRC cobalt assets, 1995 to 2001

	Company	Ownership	Assets
-	Gécamines	Government (100%)	West Group
-	Gécamines	Government (100%)	Central Group
-	Gécamines	Government (100%)	South Group
1995	Union Minière-Gécamines joint-venture	Union Minière (Belgium) (50%), Gécamines (DRC) (50%)	Kasombo
1997	GTL	Groupe George Forrest (Belgium) (50%), Gécamines (DRC) (50%)	Luiswishi
2001	Kababankola Mining Company	Tremalt (Isle of Man/BVI) (80%), Gécamines (DRC) (20%)	Kakanda

Source: Authors construction. Based on Carter Centre (2017); Roskill (2007)

Note: White rows denote no foreign ownership and green rows denote some foreign ownership. Domiciles, start dates and ownership stakes are shown where available.

7.1.1.3 FDI increases after new Mining Code (2002 to 2006)

Joseph Kabila assumed the presidency in January 2001 following the assassination of his father, Laurent-Désiré Kabila. Unlike his father, Joseph Kabila welcomed international assistance including financial support from the World Bank and IMF. In part to appease the World Bank and its preference for a standardised legal framework for mining sector privatisation, new mining legislation was put in place in 2002 (Carter Centre, 2017). The new Mining Code, adopted in 2002, and its ancillary Mining Regulation, adopted in 2003, thoroughly modified and reshaped the legal system applicable to mining rights in the DRC (Hubert, 2007).

The 2002 Mining Code (discussed in more detail in chapter 8) instituted a standardised, competitive, liberal regime by which the state would regulate and supervise the sector and private operators would be responsible for actual mining operations (Carter Centre, 2017). New operators were to negotiate terms with the Mines Registry (CAMI) responsible for allocating titles on a first-come, first served basis, using predefined, objective technical and financial criteria (Carter Centre, 2017). By 2007, the Mines Registry had issued 471 exploitation permits with private companies holding roughly 35% and the rest held by state-owned companies to some degree (Carter Centre, 2017). Thus, while the Mining Code was intended to liberalise the sector, Gécamines, a state-owned enterprise, retained large amounts of control.

While the Mining Code didn't grant special powers to state-owned enterprises, Gécamines position was ultimately preserved because of a stipulation of the Mining Code intended to attract investors. The Mining Code stipulated that payments to the state were not due until after production had commenced. Thereafter, royalty payments were to begin, and only once a company became profitable enough to overcome initial losses, was a tax to be paid on profits (Carter Centre, 2017). As a result, and with mine production at all-time lows in 2002, the treasury couldn't expect major income from the mining sector for several years. Thus, the only way to secure funds through FDI was the receipt of signing bonuses. The only way to get a signing bonus or other additional revenues before production was to organise a public tender to sell or dispose of a mining asset, although the Mining Code restricted that possibility to exceptional cases (Carter Centre, 2017).

The Mining Code, however, stated that state-owned companies were allowed to retain ownership of a certain number of permits and so Gécamines converted its most valuable assets into new Mining Code exploitation titles (Carter Centre, 2017). Thus, Gécamines remained the gate-keeper to the most important copper and cobalt deposits in the country. The Mining Code also allowed titleholders, including state-owned companies, to sell or lease their Mining Code titles to other companies (Carter Centre, 2017). As such, Gécamines privatised some of its titles and partially privatised others, ceding some control to partners in joint venture companies in which it maintained a stake (Carter Centre, 2017). In effect, therefore, a two-tier system emerged with Gécamines holding rights to all the best assets and CAMI holding the remainder. As the Carter Centre (2017) found, the Mining Code:

> "…left room for the continuation of negotiations and politicised deal-making — not directly with the Congolese government, but with its state-owned companies. Its transitional provisions effectively institutionalised the power of Gécamines and those who had a say in its management to distribute the country's best titles without public tendering, relying on provisions that regulated title transfers from one investor to another rather than from the state to a private party. Just like before, Gécamines' permits could be used to compensate local construction companies for roads they had built or to reimburse foreign arms traders for the military assistance they had provided".

With the new mining code in place, there was a flurry of joint-venture agreements signed with Gécamines up to 2006 (Table 30). Some deals were relatively transparent. For example, Chemaf was founded in 2001 and became the licensee of the *Etoilé* mine after acquiring a share in the concession from Gécamines in November 2003 (Roskill, 2007). Shalina Resources held an 80% stake in the operation and Gécamines maintained a 20% minority stake.

Other deals were far more complicated as is the case with Mukondo Mining. In April 2004, President Kabila had transferred the Mukondo copper-cobalt deposit into a 50:50 joint venture, the Congo Resources Joint Venture (CRJV), between Billy Rautenbach and John Bredenkamp, both Zimbabwean businessman (Roskill, 2007). The former had served as chairperson and managing director of Gécamines since 1998.[1] In February 2006, LSE-listed Central African Mining and Exploration Company (CAMEC) purchased International Metal Factors Ltd for US$25M, and in doing so acquired 75% of Billy Rautenbach's share of the Mukondo deposit (Roskill 2007; RAID, 2012). In July 2006, CAMEC purchased Majestic Metal Trading Ltd for US$25.8M and acquired the remaining 25% of Rautenbach's share of CRJV and, therefore, 50% of the Mukondo deposit (Roskill 2007; RAID, 2012). Through its Prairie International Limited subsidiary, Dan Gertler International Group (DGI) acquired John Bredenkamp's share, and the remaining 50% of the Mukondo deposit, the same year (Roskill, 2007; RAID, 2012).

This example highlights the increasing level of complexity associated with mine ownership in the DRC. Mines were often held through a string of offshore firms, principally to avoid tax liabilities. Certain foreign firms, notably *Groupe George Forrest* and Fleurette Group (associated with Dan Gertler International) were involved in multiple operations.

Table 30 shows a list of all known instances of FDI in DRC cobalt assets between 2002 and 2006. During this period, firms from Canada, China, the Isle of Man, Israel, South Africa, the UAE, the UK, and the USA undertook investment into Congolese cobalt assets.

[1] In 2001 and 2002, Rautenbach and then Bredenkamp were reported by the UN for their alleged involvement in funnelling profits from mines in the Democratic Republic of the Congo back to Mugabe. The deals were said to be payment for Zimbabwean military support during the DRC leader Laurent Kabila's violent rise to power (The Guardian, 2016).

Table 30: FDI in DRC cobalt assets, 2002 to 2006

	Company	Ownership	Assets
2003	Chemaf	Shalina Resources (UAE) (80%), Gécamines (DRC) (20%)	Etoilé
2004	Mukondo Mining	DGI (Israel) (50%), CAMEC (UK) (50%)	Mukondo
2004	CMSK	Gécamines (99%), Unknown (1%)	Luiswishi
2005	Ruashi Mining	Ruashi Holdings (South Africa) (80%), Gécamines (DRC) (20%)	Rushahi, Musonoi East, Sokoroshe
2005	Kamoto Copper Company	Gécamines (DRC)	Kamoto
2005	Tenke Fungurume Mining	Freeport McMoRan (USA) (56%), Lundin Mining (Canada) (24%), Gécamines (DRC) (20%)	Tenke Fungurume
2005	DRC Copper and Cobalt Project (DCP)	Nikanor (Isle of Man), Gécamines (DRC)	KOV
2005	Minière de Kalumbwe Myunga (MKM)	China National Overseas Engineering (China) (71%), Gécamines (DRC) (17.5%), EXACO (DRC) (11.5%)	Kalumbwe-Myunga
2005	Anvil Mining Concentrate (AMCK)	Gécamines (DRC)	Kinsevere
2005	Compagnie Minière de Musonoï (COMMUS)	China National Overseas Engineering (China), Gécamines (DRC)	Musonoï
2005	Compagnie Minière de Kasombo (MIKAS)	Gécamines (DRC)	Kasombo
2005	Feza Mining	Wanbao Resource (China) (51%), COMIDE (49%)	Kamoya
2006	Compagnie Minière de Luisha (COMILU)	China National Overseas Engineering (China) (72%), Gécamines (DRC) (18%)	Luisha
2006	CDM	Huayou Cobalt (China) (98%), Huayou Hong Kong (Hong Kong) (2%)	Kambove, Luiswishi, Mikas

Source: Authors construction. Based on Carter Centre (2017); Roskill (2011)

Note: White rows denote no foreign ownership and green rows denote some foreign ownership. Domiciles, start dates and ownership stakes are shown where available.

7.1.1.4 FDI continues (2007 to 2017)

Over the following decade, FDI continued as shown in Table 31. It was mostly during this period that the lead firms that characterise the modern cobalt sector took control of their assets. Tenke Fungurume Mining (TFM) became a joint venture between Freeport-McMoRan Copper and Gold (56%) of the USA, Lundin Mining (24%) of Canada, and Gécamines (20%). The company had been established in 1996 under the DRC Companies Act for the purpose of developing the deposits of copper, cobalt and associated minerals under the control of FMC (Lundin, 2017). However, a series of complications including civil unrest and allegations of bribery meant that no development took place for more than a decade (Custer and Nordbrand, 2008). First cobalt production was in 2009. Freeport-McMoRan Copper and Gold sold its majority stake in Tenke Fungurume Mining to China Molybdenum (CMOC).

Boss Mining was formed in 2005 as a joint venture between Shaford Capital and Gécamines (Roskill, 2014). In 2007, CAMEC acquired Shaford Capital's 70% stake. Following a government-imposed renegotiation of contracts in 2008; Mukondo Mining Company and Savannah Mining Company were absorbed into Boss Mining (Roskill, 2014). In 2009, ENRC of Kazakhstan acquired CAMEC, including its 70% share in Boss Mining. Gécamines held the remaining 30%. The company owned and exploited concessions located around Kakanda.

This period also saw the world's biggest cobalt producer, Glencore, enter the fray. The KOV mine and Kamoto mine were run as a single operation by Gécamines from 1960 to 2000 when war and embezzlement caused mining to grind to a halt (FT, 2007). The government split the assets and sold Kamoto to Groupe George Forrest and sold KOV to a group of Israel-based investors including Dan Gertler, who renamed the business Nikanor (FT, 2007). Nikanor and Katanga Mining (a subsidiary of Groupe George Forrest) unveiled a US$3.3bn merger that reunited the two neighbouring mines in 2007 (FT, 2007). In December 2008, having lost 97% of its market value over the previous six months, Katanga Mining agreed to issue more than a billion new shares and hand what would become a stake of 74% to Glencore (Reuters, 2011). Glencore was a minority shareholder in both Nikanor and Katanga Mining. By 2013, Glencore held 75.2% of the issued and outstanding shares of Katanga Mining while Gécamines owned the other 25% (Roskill, 2014). Glencore also owned 69% of Mutanda Mining by the end of 2013, having purchased stakes from Samref Overseas and Groupe Bazano (Roskill, 2014). The remainder was held by Rowny Assets Limited (a subsidiary of Dan Gertler's Fleurette Group) which had acquired Gécamines stake in the company in 2011 (Roskill, 2014). In 2016, Glencore increased its stake in Katanga Mining to 85% and acquired Fleurette Groups' stake in Mutanda Mining to bring its share to 100%.

These Western lead firms were joined by more and more Chinese entities as the decade to 2017 progressed. Investment from Chinese entities took several forms. In one notable case, a minerals-for-infrastructure deal was struck between the DRC and China in 2007. The joint-venture company created, *Sino-Congolese des Mines* (Sicomines), is discussed in detail in chapter 8.

In other cases, Chinese mines were set up solely with the task of sourcing feedstock for refineries in China, rather than engaging in mining. Of key importance is the emergence of CDM, a subsidiary of China's Huayou Cobalt, the world's biggest producer of refined cobalt. CDM serves to provide its parent company's Chinese assets with cobalt feedstock and operates its own mine and buys cobalt from traders, who buy directly from artisanal miners in the DRC (Roskill, 2018). According to Amnesty International, multiple sources identified CDM as the largest single buyer of cobalt that originates from artisanal mines in and around Kolwezi (Amnesty, 2016). No Congolese firm has a stake in the operation.

Significant amounts of other Chinese FDI saw the establishment of new mines and processing plants. For example, Metal Mines, established in 2007, operated three copper and cobalt mines by 2013, providing feedstock which was exported to the refineries of its parent company Han Rui in China (Roskill, 2014). The projects were put into trial production at the end of 2010 (Asian Metal, 2011). Another Chinese firm, China National Overseas Engineering Corp (71%), partnered with Gécamines (17.5%) and another DRC entity, EXACO (11.50%), to form Mining of Kalumbwe Myunga (MKM). MKM operated the Kalumbwe-Myunga copper-cobalt mine (Roskill, 2014). Further, Metorex, a fully owned subsidiary of the Jinchuan Group, China, acquired Ruashi Mining for US$1.1Bn in 2011. While these two Chinese firms had partnered with Gécamines directly, it is not clear if the state-owned enterprise had any direct control over one other Chinese-led operation.

Others include EECH, which acquired its interest in Shituru from International Barytex Resources, a Canadian company, in 2009 (Roskill, 2014). Another is Feza Mining, majority owned by Wanbao Resources. Ownership of the operation has previously also been linked to Comide, DGI International and Gécamines (Roskill, 2018). It is thought that Gécamines may still maintain a stake (Roskill, 2018). Another is Huachin, which is owned by China Nonferrous Metal Mining Group, a Chinese state-owned enterprise. Several entities operate in the DRC under the Huachin name and are part-owned by CNMC's Sino-Metals Leach (SML) Zambia subsidiary. A third firm, Jiayuan Cobalt operates a mine in the DRC through its MJM subsidiary. In China, Jiayuan Cobalt produces refined cobalt. A fourth, CIMCO, operates a mine and copper smelter. Two Chinese firms own the company through a joint venture.

Table 31: FDI in DRC cobalt assets, 2007 to 2017

	Company	Ownership	Assets
2007	Boss Mining	ENRC (Kazakhstan) (70%), Gécamines (DRC) (30%)	Kakanda (various)
2007	Comide	ERG (Kazakhstan) (100%)	Various
2007	Metal Mines	Han Rui (China)	Lakasi
2007	Congo International Mining Corporation (CIMCO)	China Railway Group (China) (51%), Earing Source Investment (China) (49%)	Luisha
2008	Katanga Mining	Glencore Xstrata (Switzerland) (75%), Gécamines (DRC) (25%)	KTO, KOV
2011	Somika	Kalyan (India) (50%), Shukrana (India) (50%)	Aurum, Kimin, Nambulva, Luisha and Mackwacha
2012	Mutanda Mining	Glencore Xstrata (Switzerland) (69%), Rowny Assets (Unknown) (31%)	Mutanda
2014	MJM	Jiayuan Cobalt (China) (100%)	-
2014	Huachin	China Nonferrous Metal Mining Group (China)	-
2017	Tenke Fungurume Mining	CMOC (China) (56%), BHR Partners (China) (24%), Gécamines (20%)	Tenke Fungurume

Source: Authors construction. Based on Carter Centre (2017); Roskill (2018)

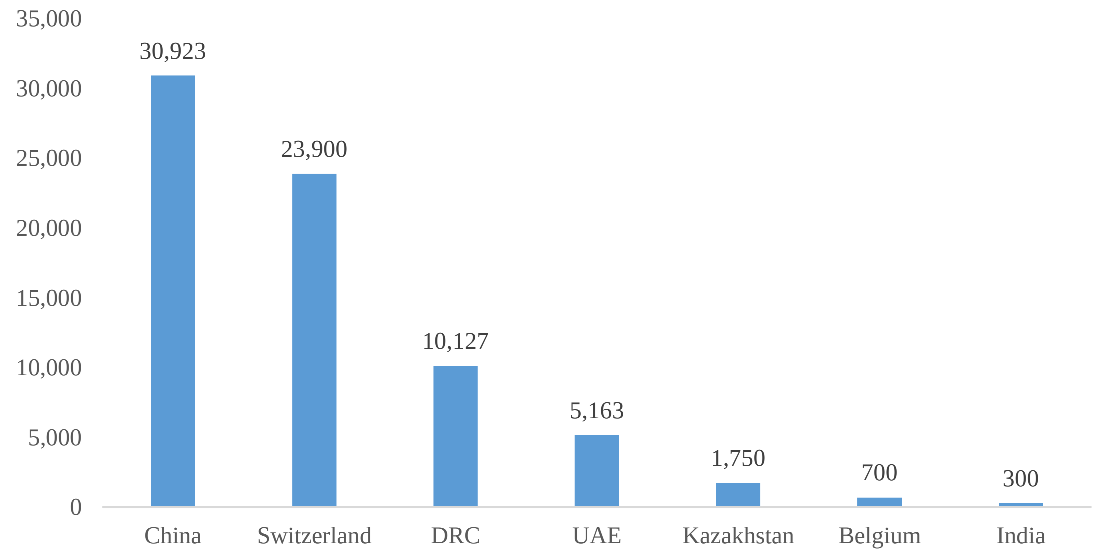
Note: White rows denote no foreign ownership and green rows denote some foreign ownership. Domiciles, start dates and ownership stakes are shown where available.

7.1.1.5 Summary

From 1967, when Belgium's UMHK was nationalised, until 1996 when a Belgian-Congolese joint-venture company started cobalt production, all cobalt output in the DRC was from one domestic producer. The civil war in the country led both the government and opposing rebels to promise mining concessions to international investors in return for finance. After the introduction of a new Mining Code in 2002, a flurry of deals were signed with international investors. However, certain elements of the new Mining Code, coupled with the government's desire for up-front payments for its mineral concessions created a situation in which state-owned miner Gécamines acted as a gatekeeper to the country's major cobalt and copper deposits. From 2006 onwards, Gécamines entered joint ventures with foreign mining companies or sold entire operations to foreign firms.

By 2017, 42% of DRC cobalt mine production in tonnage terms can be attributed to Chinese firms. A further 33% can be attributed to one Swiss firm, Glencore, the single-largest producer of cobalt in the world. DRC firms, by comparison, accounted for 14% of cobalt mine production in 2017 (down from 100% in 1995).

Figure 38: DRC cobalt mine production by firm ownership domicile, 2017 (t Co)



Source: Author's construction

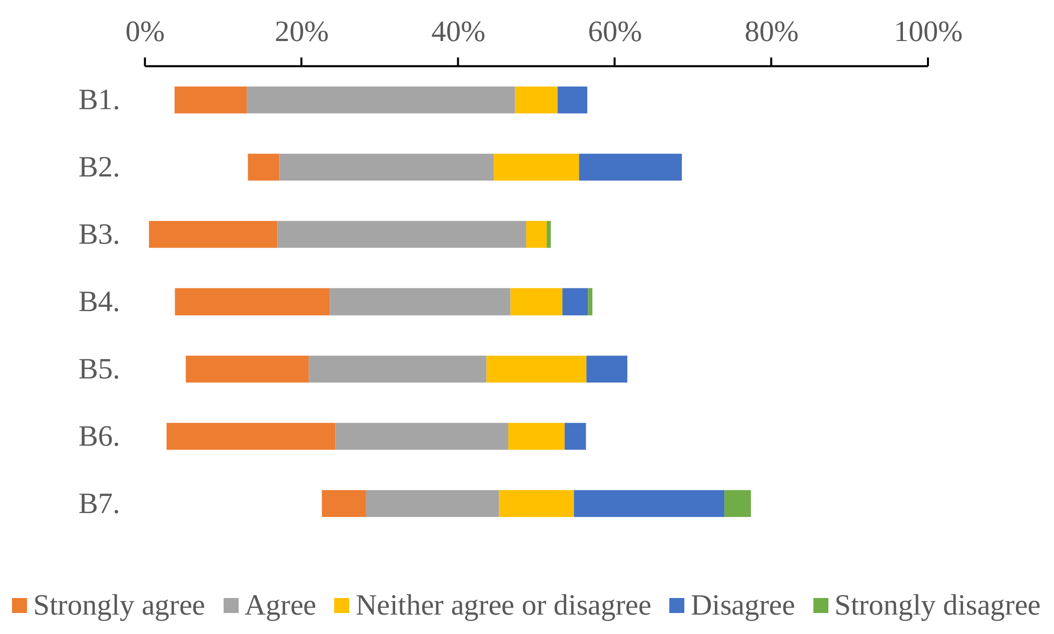
Note: Artisanal (non-firm) supply has been discounted

7.1.2 Have firms undertaken FDI in response to cobalt's criticality?

This subchapter sets out the research findings from the cobalt-sector survey and subsequent interviews with regard to answering RQ3: how have firms responded to supply risk and economic importance? Table 32 shows survey respondents views on specific statements related to FDI in the cobalt sector. These responses are charted in Figure 39 and Figure 40.

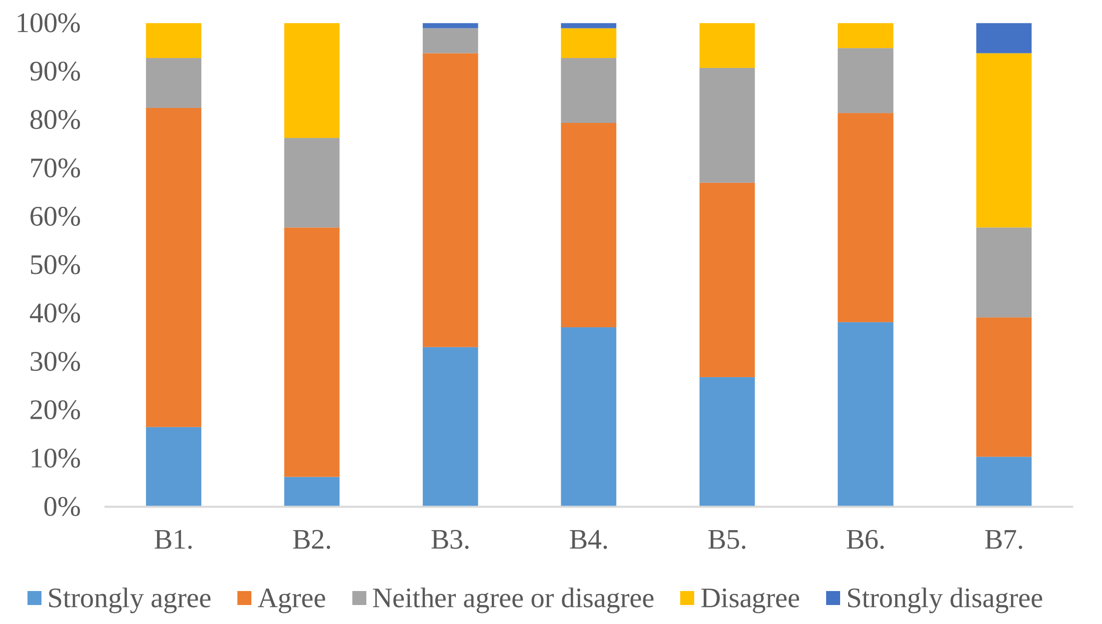
Table 32: Cobalt sector-survey results (Part B)									
	Number of respondents					Statistical tests			
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree	n	t-test	p-value	Is the result significant at p< .10
B1. Concerns over "supply risk" have motivated firms to undertake foreign direct investment in cobalt assets	17	63	10	7	0	97	11.97	0.00001	Yes
B2. "Supply risk" is the main reason for firms having undertaken foreign direct investment in cobalt assets	6	50	18	23	0	97	4.02	0.00006	Yes
B3. "Economic importance" and expectations of future demand growth are major reasons for firms having undertaken foreign direct investment in cobalt assets	33	58	5	0	1	97	19.12	0.00001	Yes
B4. "Economic importance" and expectations of future demand growth are the main reasons that firms have undertaken foreign direct investment in cobalt assets	37	41	12	6	1	97	12.20	0.00001	Yes
B5. Foreign direct investment in cobalt assets has increased over the past ten years because of concerns related to the future availability of economic cobalt resources	27	38	23	9	0	97	9.21	0.00001	Yes
B6. Foreign direct investment in cobalt assets has increased over the past ten years because of expectations regarding future demand of cobalt	38	41	13	5	0	97	13.38	0.00001	Yes
B7. Foreign direct investment in cobalt assets is principally driven by a firm's copper or nickel requirements	10	28	18	35	6	97	0.54	0.29522	No
Note: n=97 respondents									

Figure 39: Cobalt sector-survey results (Part B)



Note: 97 respondents

Figure 40: Cobalt sector-survey results (Part B)



Note: 97 respondents

A key aim of the research was to explore how cobalt's criticality, its economic importance and supply risk, has impacted firm behaviours. This sub-chapter looks to identify whether the recent foreign direct investment in the cobalt sector, labelled by one cobalt project developer (R15) as an "…explosion of foreign resource companies focussed on developing cobalt resources", was caused by firms responding to cobalt's criticality. Part B of the cobalt-sector survey was designed to explore this.

Survey question B1 asked whether "…concerns over "supply risk" have motivated firms to undertake foreign direct investment in cobalt assets". A total of 82% of respondents agreed, or strongly agreed, with this statement, while 58% considered supply risk "…the main reason for firms having undertaken foreign direct investment in cobalt assets" (survey question B2). As an investment banker with exposure to cobalt equities (R4) put it:

"Yes, of course, companies are investing in these assets because they need security of supply. Everyone thinks that future demand for cobalt is going to be huge and they [firms] are moving to lock in their supply now through investment or offtake. There are now dozens of cobalt projects that have attracted investment, but the big ones are all in the Congo".

One analyst (R1) went as far as to argue that "…profit and revenue are secondary – if you don't have cobalt you don't have a business". A retired cobalt trader (R9) made a similar point, saying that "…if they [cobalt refiners and end-users] didn't secure the cobalt for their batteries, they would be out of business completely". The same trader summarised his position by saying that "…the bottom line is economic but to protect the bottom line you need to protect the supply line". An integrated cobalt producer (R29) noted that "…few invest in cobalt mines because they think they can make more profit, it's strategic protection by necessity". These views were echoed by another cobalt trader (R14) who commented that:

"Most of the investment in Congo has been to secure the units, not even so much to make a huge profit out of mining and refining because I don't think that's considered a huge problem. It's mainly to make sure they can source secure access to cobalt units".

These interview responses, together with survey results, suggest that supply risk is a key determinant of foreign direct investment in the cobalt sector. Respondents, almost exclusively, referred to FDI in the DRC rather than in other jurisdictions, with most outlining their views on Chinese FDI, rather than investment from firms in other countries. An integrated cobalt producer with operations in Africa (R17) focussed in on investment from the owners of Chinese refineries, suggesting that while these plants are major consumers of cobalt, access to it was not secure:

"In China, the refineries account for 60% of cobalt consumption but mine assets are owned by foreign companies so it's not secure for them. If they get the opportunity directly own these assets, of course, they want to go for this investment".

While supply risk was reasoned to be a key factor underpinning FDI in the cobalt sector, several interview respondents also talked of other types of risk. One Chinese executive at a mine in Lubumbashi (R25) said, "…supply risk isn't just about access for companies anymore. We have to ensure that the cobalt being bought is clean". The respondent was referring to the high-profile issue of child labour in the cobalt sector, and the negative impact that association with this reality has on implicated firms. Public understanding of the importance of sustainable procurement and the issues related to child mining in DRC has increased in recent years. UNICEF estimated in 2014 that approximately 40,000 boys and girls work in all the mines across southern DRC, many of them involved in cobalt Mining (Amnesty International, 2017). Media and NGO attention on this issue has prompted many end-users of cobalt to improve its sourcing methods (Onstad, 2017). One analyst (R2) summed up the situation as follows:

"There is huge reputational risk if you're associated with child mining, and rightly so, but still it happens, and no one has ever gone under because of it. It still goes on and it's abhorrent but it's a reality. And when the cobalt price is high it's even more of a reality".

By drawing attention to this reputational risk, or corporate social responsibility risk, this comment serves to highlight how the risk environment surrounding cobalt mining has evolved in recent years and as such how the motivations for FDI have also evolved. As one cobalt trader (R10) noted, "…twenty years ago, people wanted access because you could make millions by operating where no-one else would [the DRC]. But today it's mostly getting hold of a steady flow of cobalt". When foreign investment in DRC cobalt assets first began, in the early 2000s, the motivation of foreign firms was principally that of access to raw materials and profit making. Today, security of supply and sustainable supply are primary factors. A European automotive producer (R33) noted that "…as EV producers we need clean cobalt. Sustainability is essential. The DRC isn't an option. Yet it is the only option". A major Japanese trading company (R34) agreed that "…for us [Japanese firms] the Congo is not really an option. Japanese companies will not tolerate the risks".

Research findings suggest that, like supply risk, economic importance was believed to be a key motivation for FDI in the cobalt sector. In total, 94% of respondents to the cobalt-sector survey agreed, or strongly agreed, that "economic importance" and expectations of future demand growth are major reasons for FDI (survey question B3). Indeed, 80% agreed, or strongly agreed, that "…economic importance" and expectations of future demand growth are the main reasons that firms have undertaken foreign direct investment in cobalt assets" (survey question B2).

An integrated cobalt producer (R17) reasoned that "…because cobalt is so important to China and because they [China] have such high demand, it makes sense for them to invest and secure their feed for the future." An end-user of cobalt (R6), was well placed to highlight why cobalt's economic importance has been a key driver of foreign investment:

"Demand for cobalt is booming. It's one of a handful of metals that will make or break the electric vehicle story. While there is lots of talk about reducing cobalt content in NCM [nickel-cobalt-manganese] cathodes, that's years away. If we want EVs we will need cobalt".

A common theme in interviews was that while cobalt's economic importance was global, it was most acutely felt in China. Firstly, this is because China is home to the majority of the world's cobalt refineries, which require cobalt units to process. Secondly, it is because China is a major producer of portable electronics, and especially, electric vehicles (EVs). Many interview respondents made the link between economic importance and EVs specifically. An experienced industry professional (R16) argued that in recent years, cobalt's economic importance had increased exponentially and fundamentally changed the sector. He suggested that:

"The whole dynamic of the cobalt market has changed…cobalt was a modest market, almost a curiosity metal, the paradigm shift now is immense because of the rapidity with which the electrification of mobility has taken place has completely changed the dynamics of the market. We are looking at a totally different market to three years ago. Totally different. This is a driver behind direct investment".

Another common theme in interviews was that because of the advent of the electric vehicle age, the last few years represented a step change in cobalt's global importance. A geologist (R7) agreed that recent changes represented a paradigm shift and that cobalt's increasing economic importance had led to FDI:

"Markets are fundamentally changing, incorporating minor metals like cobalt into mass markets. Low volume metals – when they enter a large market – puts strain on the existing supply base as they haven't seen demand on this scale. Companies are aware of this and the supply risk of the metals they need. The key point here is automotive is a large market and cobalt is now hugely important to its future. We have seen FDI in order to secure feedstock as everyone is aware of the scale of demand coming from automotive".

As shown in Part II, the demand for cobalt in batteries increased between 2000 and 2015 principally because of the growth in portable electronics, which used cobalt in the cathodes of the lithium-ion batteries that power them. More recently, it has been the expectation that EVs will require huge amounts of cobalt that has intensified the scramble for the metal through FDI.

A common theme in interviews was that Chinese firms had invested in the DRC cobalt sector before those from other jurisdictions. One trader (R14) noted that Chinese investors identified opportunities in the DRC first, saying "...the Chinese saw the opportunity and requirement for cobalt in EVs a few years ago, so their investment is ahead of anyone else". A geologist (R7) posited that "…eventually you may see more investment in Congo [from non-Chinese firms] and there are some non-Chinese entities starting [to invest] but they are way behind the Chinese". Similarly, a Director at a North American mining project (R13), suggested that some Chinese firms had begun to undertake FDI in response to anticipated cobalt demand several years ago:

"Chinese companies were early to recognise the broader scale realities of automotive electrification and battery material supply around 2013 to 2016. They were proactive in making acquisitions such as the Tenke-Fungurume purchase as well as a number of projects that were developed in the Congo by Chinese companies such as China National Railway and Huayou".

This suggestion that Chinese firms entered the DRC first does not tally with the analysis in chapter 7.1.1, which shows that European firms were the first to invest in the Congo. Nonetheless, the analysis did show how western lead firms were joined by more and more Chinese entities as the decade to 2017 progressed and Figure 38 shows that in 2017, 42% of DRC cobalt mine production in tonnage terms could be attributed to Chinese firms. As one academic (R8) mused, "…at the moment, it's one country dominated when it comes to foreign direct investment. Seven out of ten of the major producers in the DRC are from China". Another interview respondent (R9) outlined the reason behind this, simply by saying that "…as a nation, China has not hesitated to put money on the ground and to try and secure their own supplies". Another cobalt trader (R14) attributed Chinese investment in the Congo to a high tolerance for risk:

"There has been increased scrutiny on methods of doing business, you have seen this with Glencore (DOJ) and ERG (SFO). China don't have the same concerns over political risk. There is a belief that the Chinese government holds so much sway over African governments that if there are any major disputes, they can get them resolved to their satisfaction".

The analysis above shows how cobalt's criticality can be said to have influenced foreign direct investment. However, interview respondents also articulated various other factors that could be said to be key justifications for FDI in DRC cobalt assets. Some, such as geologist based in London (R7), reasoned that the FDI was more a feature of the Chinese "Go Out (走出去)" policy:

"The Chinese government…gives good financing support to own foreign assets. The Chinese have to spend the currency as they don't want all the money going back to the Central Bank, so they encourage people to take a loan and spend US dollars outside of China".

This argument was supported by a journalist (R12), who thought that "…China's Go Out (走出去) policy is a very important factor. Before that, the Chinese [firms] couldn't compete with [firms in] developed countries".

The consensus among interview respondents was certainly that Chinese investment dominated the cobalt landscape. Many respondents also noted that numerous key actors in the supply chain had yet to invest in the sector. One European automotive producer (R6) commented that "…up to now, investment has been from Chinese capital backed refined producers, but the big tech firms, banks and finance companies are waiting in the wings". Indeed, most interview respondents agreed that there had been foreign little investment from end-users of cobalt. One producer (R5) noted that "…so far there is zero direct investment from those [electric vehicle] guys". Another industry expert (R16) suggested that EV producers were contemplating investment. His view was that "…automotive companies are thinking about their supplies and investing in producing. [If they do] …they know where it's [cobalt supply] coming from, they know it is being sourced responsibly, and they have assured supply". A retired trader (R9) reasoned that unlike Chinese investors and refined producers, automotive companies lacked the risk appetite and to invest in the DRC:

"The automobile companies were looking at direct investment in the producing countries, in the extreme case in Congo, and if not in places that are strategically less risky be it Australia or the Philippines or Canada or wherever else….but I think there has been a retrenchment as they have realised…it was one step too far in terms of administration, technical and political exposure and being out of their core area of knowledge…I think they have made the general decision to pass the buck of responsibility of raw material supply to the battery makers in Korea, Japan, or Europe. The one exception, where there has been from a nation, a rush to make direct investments to control their own fate in cobalt supply, has been China, and China particularly in Congo".

One European automotive producer (R18) confirmed that his company had explored the potential for investment in the Congo but had held back:

Speaking as a car guy, we have analysed undertaking FDI but didn't do it in the end. But others have been heavily investing. I surprised more haven't. There is a difference between short- and long-term strategies. Some are just trying to suck in as much stock as they can right now. Others have long-term strategies and are investing".

An integrated producer elsewhere in Africa (R31) noted that "…the EV guys are now very interested in offtake of our cobalt. Probably because it's not seen as risky like the Congo. Some are interested in long offtake deals, which is encouraging".

As well as China's "Go Out (走出去)" policy being a key reason for FDI in the cobalt sector, some interview subjects argued that FDI was mainly governed by copper and nickel exploration. As shown in Part I, cobalt is mined almost exclusively as a by-product of copper and nickel mining and thus the supply of cobalt is heavily dependent on demand for and subsequent supply of these base metals. One project developer (R13) noted that:

"As late as 2016, nobody even really cared about cobalt and figured that it was a niche minor metal that comes along for the ride in copper and nickel mining and refining. The supply-side risks were not recognised or [were] underestimated".

One analyst (R1) said that:

"…cobalt is important, and of course you want the cobalt credit, but really these are still copper mines and copper deposits. Glencore, the Chinese, they are after the copper and the cobalt but up until now, but not so much recently, it has been more about the copper".

This view appears reasoned and sensible. The economics of most copper and nickel operations are dependent upon the revenues derived from the sale of those metals. Cobalt, while bringing a useful credit, is not often fundamental to the economics of an operation. However, only 39% of respondents to the cobalt-sector survey agreed or strongly agreed with survey question B7 which suggested that "…foreign direct investment in cobalt assets is principally driven by a firm's copper or nickel requirements". This may be because the survey focussed on cobalt-sector actors (a survey of copper-sector actors may have championed copper's importance more). Or because the survey was completed during a period of high cobalt prices.

7.1.3 Summary

The preceding subchapter was concerned with RQ3 which asked: how have firms responded to perceived resource scarcity and demand growth? In particular it sought to explore the hypothesis set out in Part I (chapter 3.5) that firms would have engaged in foreign direct investment (FDI) and resource-seeking in response to cobalt's criticality. RQ3 was set, and this subchapter was intended, to help meet the broader research aim of understanding how firms have responded to cobalt's criticality, and how these responses have resulted in spatial and structural outcomes.

The outcomes are clear: firms, particularly Chinese firms, have engaged in FDI and resource seeking, especially in upstream DRC copper and cobalt assets. The results of the cobalt-sector survey indicate that firms have engaged in FDI and resource-seeking as a direct result of cobalt's criticality. For example, survey question B5 asked whether "…foreign direct investment in cobalt assets has increased over the past ten years because of concerns related to the future availability of economic cobalt resources" and a total of 67% of respondents agreed, or strongly agreed, with this statement. Similarly, survey question B6 asked whether "…foreign direct investment in cobalt assets has increased over the past ten years because of expectations regarding future demand of cobalt" and 81% of respondents agreed, or strongly agreed, with this statement.

As discussed in the literature review (chapter 3.3.2), various theories have been put forward to explain the determinants of FDI. These include a motivation to achieve higher returns in foreign markets through lower labour costs and exchange risks; ownership benefits, economies of scale and incentives; and oligopolistic and behavioural drivers based on following competitors into foreign markets (Assunção, et al., 2011). One particularly important contribution was Dunning's (1988) "ownership, location, and internalisation (OLI)" approach, which suggests that three advantages that can underpin a firm's decision to become multi-national.

Dunning's framework fits neatly with observations on the cobalt sector and FDI in the DRC specifically. The ownership advantages in a cobalt-sector context are fundamentally secure access to the required raw material feedstock. As one interview respondent (R9) noted "…the bottom line is economic but to protect the bottom line you need to protect the supply line". Location advantages in this context are somewhat driven by geology, although it can be said that those firms that have undertaken FDI in the DRC would also benefit from certain economic, institutional and social advantages. In some cases, these advantages were underhand. Over the period under analysis, it is clear that certain actors saw an economic advantage in dealing with DRC institutions with "...tens-of-millions of dollars… exchanging hands in return for mining licenses that were going sideways either to Switzerland or into private election funding (R9). Internalisation advantages mainly include owning cobalt assets rather than being required to purchase cobalt units on a volatile open market.

The GPN literature also offers explanations for FDI. This literature posits that by responding to various dynamic pressures and incentives, actors conjure global networks to create, enhance and capture value. Thus, lead firms like Huayou Cobalt or Glencore touch down in regions and engage in bargaining and cooperation with regional actors on the basis that this supports their strategic needs. This is a mutually beneficial relationship termed strategic coupling, a "…mutually dependent and constitutive process involving shared interests and cooperation between two or more groups of actors who otherwise might not act in tandem for a common strategic objective" (Yeung, 2009: 332). FDI represents a form of such 'cooperation' and serves both the interest of the lead firm (e.g. access to cobalt units) and the institution (tax revenue, job creation etc.) As Pavlinek (2018) notes, strategic coupling is very much dependent on the existence of surplus capital looking for investment opportunities abroad and spatiotemporal fixes around the world.

Central to this dissertation is the question of whether criticality a causal dynamic. Has it shaped the structure and geographies of supply chains? Based on the responses of some firms, and some of the findings of this chapter, the answer is 'yes'. Supply risk and economic importance are shown to be determinants of FDI decisions. But of course, not all lead firms in the cobalt GPN (for a list see Table 6, chapter 3.4.3.2) have engaged in FDI in the DRC, or at all. This begs the question, why has criticality prompted some firms to undertake FDI but not others?

The findings of this sub-chapter suggest that alongside criticality, other factors, too, are motivations and requirements for FDI. In particular, the Chinese regulatory environment and the pursuit of copper and nickel units were highlighted as key factors. The analysis has shown that FDI in the cobalt sector has principally been undertaken by Chinese refined producers of cobalt, supported by Chinese financial institutions and the Chinese regulatory environment. If criticality can be said to be a motivating factor behind FDI, such regulatory and financial support represent enabling factors. Not all lead firms have the ability to undertake FDI. Furthermore, not all firms want to. Despite the huge interest in cobalt procurement because of the anticipated demand from the electric vehicle sector, there has been limited FDI from end-users of cobalt such as automotive firms, especially ex-China firms. For the most part, it has only been Chinese firms that have shown the risk appetite and to invest in the DRC (see section 7.1.2). Numerous other firms have taken the opposite approach, seeking to distance themselves, both their supply chains and their reputations, from the Congo. These points will be further discussed in the dissertation's conclusions.

7.2 Integration in the cobalt sector

A second hypothesis set out in Part I of this research was that in reaction to cobalt's criticality, firms would have vertically integrated both forwards and backwards. Vertical integration is typified by one firm engaged in different parts of production. Before examining this issue in light of the findings of both the cobalt-sector survey and semi-structured interviews, it is first useful to present a short case study in order to provide an illustrative example of integration in the cobalt sector. As such, this sub-chapter commences with a short case study on one of the lead firms identified in the cobalt GPN. Huayou Cobalt, the world's largest producer of refined cobalt. The analysis shows how, over the past decade, the company has integrated both forwards and backwards.

7.2.1 Case study: Huayou Cobalt

Huayou Cobalt was founded in 2002. Initially, the company was exclusively a refined producer focussed on the smelting of cobalt, nickel and copper. As such, it had no cobalt mines, nor did it produce any downstream products such as battery materials. Feedstock was initially sourced from third parties and thus the cobalt was reliant on external actors for its cobalt supply.

To secure its supply of feedstock, the company began cobalt and copper resources exploration and development in Africa from 2006 (Huayou Cobalt, 2015). That year, the company set up Congo Dongfang International Mining (CDM), a wholly owned subsidiary in the DRC, and in 2007, CDM put a pyrometallurgical plant in the DRC into operation. By May 2007, the company reportedly had mining licences over 19 properties in the DRC (Metal Bulletin, 2007). CDM's supply chain is described by Amnesty International (2016)[1] as follows and in Figure 41 :

"CDM buys cobalt from traders, who buy directly from the miners. CDM then smelts the ore at its plant in the DRC before exporting it to China. There, Huayou Cobalt further smelts and sells the processed

[1] In its 2015 report. Amnesty International (2015) found that Huayou Cobalt had failed to carry out suitable due diligence in line with OECD guidance, that it was failing to respect human rights and there is a high risk that Huayou Cobalt is buying (and subsequently selling) cobalt from artisanal mines in which children and adults work in hazardous conditions. In 2017, Amnesty International (2017) found that since January 2016, Huayou Cobalt had taken a number of steps in line with international standards including the introduction of a strategy for responsible artisanal and small-scale mining that has largely focused on addressing the risk of child labour

cobalt to battery component manufacturers in China and South Korea. In turn, these companies sell to battery manufacturers, which then sell on to well-known consumer brands".

Figure 41: Flow chart of the Huayou Cobalt supply chain, 2015

Source: Amnesty International (2015)

Investments in the DRC continued; the company acquired stakes in three mining companies in the DRC in 2008 and another in 2015 (Table 33). That same year saw the company's IPO and listing on the Shanghai Stock Exchange. Major shareholders included the China-Africa Development Fund and the China Belgium Development fund, two government funds. Other shareholders include funds controlled by commercial banks in China and Hong Kong Securities Clearing, controlled by the Hong Kong government. Huayou's subsidiary companies, together with CDM, have since continued to invest and develop their Congolese assets. In 2017, Huayou invested further in a near-term cobalt project in the DRC, Nzuri Copper as well as in a lithium project in the country.

Table 33: Huayou Cobalt – Timeline

2002	Company founded in Tongxiang Economic Development Zone, Zhejiang province
2006	Company sets up Congo DongFang International Mining subsidiary in DRC
2008	Company signs Sicomines agreement, acquires stake in MIKAS in DRC
2008	Company acquires stake in La Compagnie Miniere de Musonoie (COMMUS) in DRC
2008	Company acquires 72% stake in Minière de Kasombo (Mikas) in DRC
2015	Huayou Cobalt's IPO and listing on Shanghai Stock Exchange
2015	Company acquires Minière du Sud Katanga (CMSK) operation in DRC
2016	Company founds Huayou New Energy Technology Co. Ltd. to produce battery materials
2017	Company invests A$10M in Nzuri Copper in DRC
2017	Company invests A$13.02M in AVZ Minerals Manono lithium project
2017	Company establishes three recycling companies and acquires stakes in two others
2018	Company enters joint-venture agreement with POSCO to produce battery materials
2018	Company enters joint-venture agreement with LG Chem to produce battery materials

Source: Author's construction

Note: Orange shading denotes upstream integration, green shaping denotes downstream integration

As noted in the literature review, theories of firm structure generally suggest that functions are brought inside the boundaries of the firm when there is a benefit in doing so, and the empirical literature on vertical integration is divided into two major areas: contributions that consider the decision whether to integrate forward into retailing, and those that examine the “make or buy” decision, which is the decision whether to integrate backwards (Lafontaine and Slade, 2007). The examples above serve as evidence of how Huayou Cobalt has chosen to “make” cobalt feedstock and this has integrated backwards in the DRC.

More recently, Huayou Cobalt has also decided to integrate forwards. In 2016, the company established Huayou New Energy technology. This subsidiary company’s products are mainly applied to the field of new energy vehicles and energy-storage power sources (Huayou Cobalt, 2016). In January 2018 it was announced that Huayou Cobalt had agreed a deal to set up two joint ventures to produce lithium-ion battery materials with South Korea’s largest steelmaker, POSCO (Reuters, 2018a). It is planned for the two entities to start production of lithium-ion precursor and cathode from 2020 onwards (Reuters, 2018a). Three months later, it was announced that Huayou Cobalt had signed a similar deal with South Korea’s LG Chem, a technology firm (Reuters, 2018b). Similarly, the two joint ventures are intended to produce lithium-ion precursor and cathode respectively from 2020. Further, in 2017 Huayou set up three companies in China and acquired stakes in two more to pursue lithium-ion battery recycling. Thus, since 2016, Huayou Cobalt has actively been moving downstream, in order to become a producer of higher-value, cobalt consuming products.

In summary, when it began operating in 2002, Huayou Cobalt was engaged in only one stage of the cobalt supply chain. Through a series of investments, the company integrated backwards, investing in DRC cobalt mine and intermediate production facilities to bring the production of cobalt feedstock within the boundaries of the firm. It has also invested in recycling with the same aim. More recently, the company has moved to integrate forwards and produce lithium-ion battery precursors and cathodes rather than sell its refined cobalt products to external firms. Over this period, and in part because of its strategy of FDI and integration, Huayou Cobalt has become the world’s largest producer of refined cobalt, producing 23,720t in 2017 (Huayou Cobalt, 2017).

Here it is useful to once again return to the simplified schematic of the cobalt supply chain. Figure 13 shows how, over time, forward and backward integration has seen Huayou Cobalt extend its reach across the cobalt supply chain.

Figure 42: A simplified schematic of the cobalt supply chain (Huayou Cobalt)

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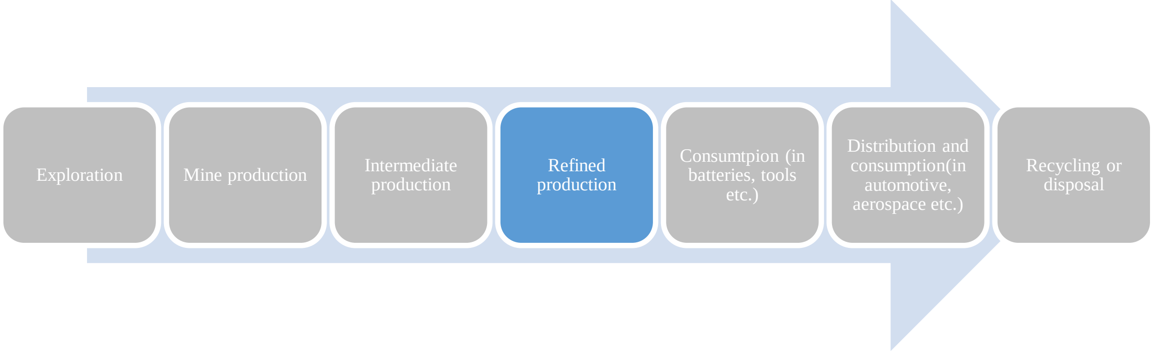
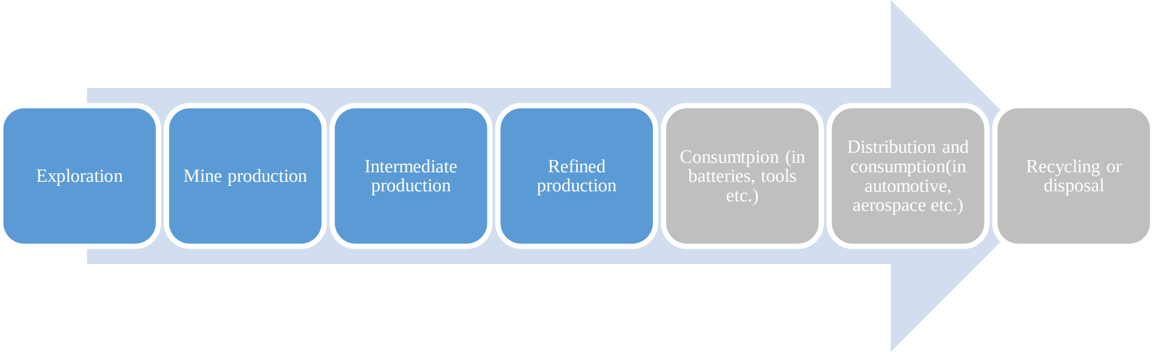
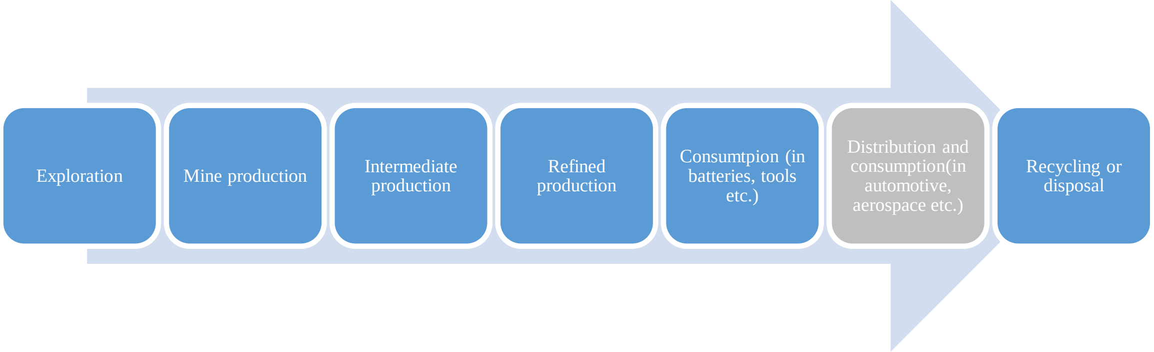
Huayou Cobalt and subsidiaries 2006



Huayou Cobalt and subsidiaries 2008



Huayou Cobalt and subsidiaries 2018



Source: Author's construction

Note: Blue boxes denote stages of the supply chain in which Huayou Cobalt is active

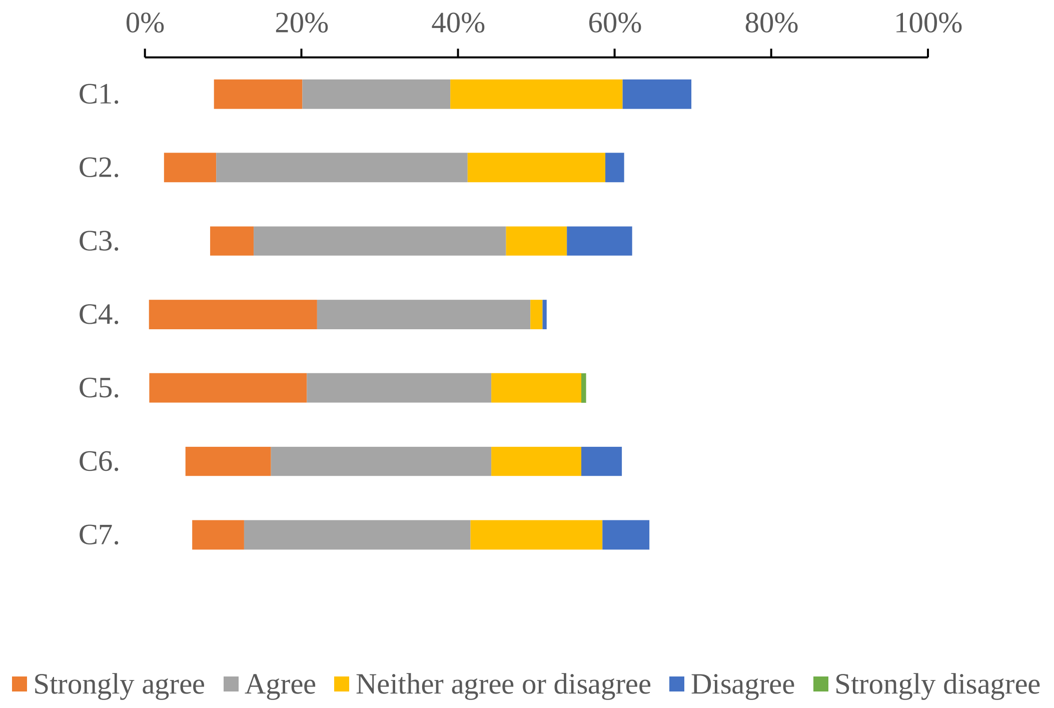
7.2.2 Have firms vertically integrated in the cobalt sector?

This subchapter sets out the research findings from the cobalt-sector survey and subsequent interviews with regard to answering RQ3: how have firms responded to supply risk and economic importance? Table 34 shows survey respondents views on specific statements related to integration in the cobalt sector. These responses are charted in Figure 43 and Figure 44.

Table 34: Cobalt sector-survey results (Part C)

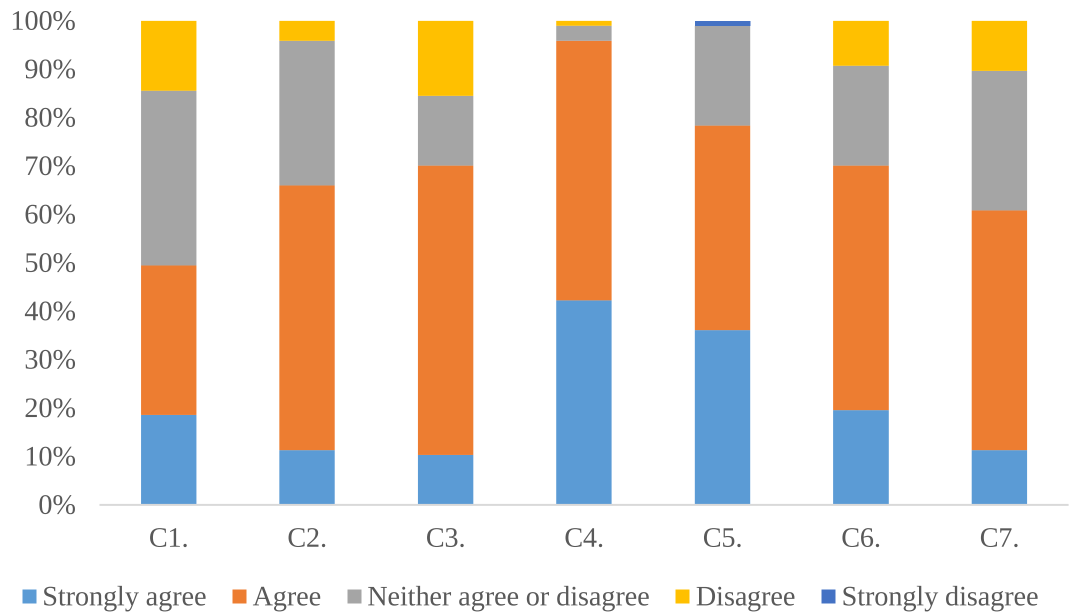
	Number of respondents					Statistical tests			
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree	n	t-test	p-value	Is the result significant at p< .10
C1. It is preferable for a refined cobalt producer to be fully integrated, rather than buy cobalt concentrates or intermediates	19	31	34	13	0	97	5.54	0.00001	Yes
C2. Concerns over "supply risk" have led refined producers of cobalt to integrate backwards, thus bringing supply of feedstock within the boundaries of the firm	11	54	28	4	0	97	10.14	0.00001	Yes
C3. Demand for cobalt and its "economic importance" has led some mine producers of cobalt to pursue production of higher-value cobalt products to capture more value	9	58	15	15	0	97	7.42	0.00001	Yes
C4. End-users (e.g. electronics/automotive OEMs) have become more involved with the procurement of the raw materials used to produce the refined cobalt products that they consume in recent years	40	53	3	1	0	97	22.60	0.00001	Yes
C5. Mine producers have become increasingly more engaged with end users of cobalt in recent years	36	42	19	0	0	97	13.79	0.00001	Yes
C6. Firms are now more likely to undertake more than one stage of cobalt production (mine, intermediate, refined, etc.) than was the case a decade ago	20	50	19	8	0	97	9.24	0.00001	Yes
C7. The cobalt supply chain has become more consolidated over the past ten years	11	46	30	10	0	97	7.45	0.00001	Yes
Note: n=97 respondents									

Figure 43: Cobalt sector-survey results (Part C)



Note: 97 respondents

Figure 44: Cobalt sector-survey results (Part C)



Note: 97 respondents

As might be expected given the analysis of FDI set out in the preceding sub-chapter, responses to the cobalt survey and semi-structured interviews confirmed that there has been considerable integration in the cobalt supply chain in recent years. One experienced industry actor (R16) noted that:

"Over the years, the market hasn't been integrated at all, but we then saw private equity going into Central Africa from publicly traded companies. The market became more disciplined after that and more integrated".

A total of 73% of cobalt-sector survey respondents agreed or strongly agreed that "…firms are now more likely to undertake more than one stage of cobalt production (mine, intermediate, refined, etc.) than was the case a decade ago" (survey question C6). Many attributed this to cobalt's criticality. A total of 67% of respondents to survey question C2 agreed, or strongly agreed, that "...concerns over "supply risk" have led refined producers of cobalt to integrate backwards, thus bringing supply of feedstock within the boundaries of the firm".

A geologist (R7), based in London, felt that "…integrating backwards solves the problems [of supply risk] as you can guarantee supply. It's related to supply risk, it's because of it". Meanwhile, the CEO of a North American cobalt project (R13) reasoned that "…there is recognition that there is a need for securing supply which is underpinning more integration". An industry pricing specialist (R11) outlined how integration and cooperation represents a hedging strategy:

"Downstream, for example precursor or cathode people, want to secure their feed; they don't want the exposure to uncertain feed for cobalt or nickel in the future so they want to go upstream to get some cooperation or some stake in the mining side, then they can hedge the risk".

A fully integrated producer of cobalt suggested that his company has been exploring new upstream and downstream cobalt assets in recent times. He (R35) noted that "…we were exploring a European refinery but decided against it this time. But we are still on the lookout for opportunities, especially in Europe". The respondent indicated that fully integrated firms are increasingly looking for wide geographic diversity as well as to undertake all stages of production. "Non-Congolese and non-Chinese operations are preferable for many customers…" they suggested.

The consensus among interview respondents was that historically, the cobalt supply wasn't too integrated. Most firms would undertake only one stage of cobalt production, for example, refined production. Thus, a refined producer's raw materials would be purchased on the open market. Cobalt's supply risk, among other factors, has led to more firms integrating backwards and bringing raw material production within the boundaries of the firm. Other types of risk were also suggested as motivations for increased vertical integration. An investment banker (R4) pointed out that agendas related to corporate social responsibility risk had changed over time which meant that integration was now more sought after:

"The Amnesty report was a game changer, but the writing had been on the wall for a while. Big tech firms were not going to be able to ignore child mining forever. Now there are hundreds of journalists looking to link these guys to illegal cobalt mining. It's still not very transparent so they can get away with it. But its better, and clearly better from a human rights perspective, to be able to prove that your cobalt is clean".

An appreciation of the importance of sustainable procurement and the issues related to child mining in the DRC has increased in recent years. Indeed, as shown in chapter 7.1.2, several interview respondents outlined this issue as a key motivation for FDI. The view that integration was related to an increased focus on raw material provenance was also outlined by a cobalt trader (R14), who said:

"In terms of why you are seeing integration between mining companies and OEMs, partly there is the scrutiny on the supply chain. Knowing where your cobalt has come from is going to be a critical part of this EV growth story.

Economic importance was also cited as a key reason for forward vertical integration. In total, 70% of respondents to survey question C3 agreed, or strongly agreed, that "…demand for cobalt and its "economic importance" has led some mine producers of cobalt to pursue production of higher-value cobalt products to capture more value". As one respondent, a Director at a North American mining project (R13), noted, "…very recently, big mining companies have started to look into investment in battery materials, waking up to the fact that there is a transformation underway that will impact commodity markets". Several interview subjects reasoned that EVs were the key factor. One retired cobalt trader (R9) suggested that:

"...cobalt producers are aware of the value chain with EVs. To capture more value in markets with growing size and competition – they have to create more value. To do that, you need to produce downstream products."

A broadsheet journalist (R12) also believed that the development of the EV sector was affecting levels of integration in the cobalt sector, noting that "…the rise of EVs have led to more integration [between actors in the cobalt sector]. The automotive guys have hired cobalt people specifically focussed on upstream". Research findings suggest that an increased awareness of cobalt's economic importance has led several actors in the supply to "…want to go and make the higher value product", as one Zambian geologist (R28) put it. As one analyst (R3) mused, "…why only mine cobalt or lithium when you can make a battery? And why only make a battery when you can make a car?"

Aside from supply risk, reputational risk, and economic importance, price stability was also mentioned in several interviews as a justification for vertical integration. One European carmaker (R6) noted that:

"The motivation has got to be stable price. Everything is predicated on trying to develop a realistic long-term price. Cobalt is now linked to the consumer in a way that you didn't use to see. Apple phones cost US$1000 because the battery costs this much etc. Consumers demand quick response and a reasonable price".

This view was supported by an analyst (R3) who believed that "…volatile prices kill off demand for so many minor metals. In many cases, consumers would accept average prices that are higher than historical averages, so long that prices were stable". Another analyst (R1), while noting that price stability was important, suggested that margin was the main reason for integration: "It's a question of margin. Is it more profitable for a refined producer to move upstream into mining and processing to capture more value, or downstream into manufacture?" This interviewee suggested that decisions to integrate were principally made in order to capture value. A refined producer (R5) linked the issues of supply risk and value capture together. The respondent highlighted how bringing more functions of production within the boundaries of the firm helped firms to mitigate supply shocks and in doing so can help protect profits. She argued that "…supply chain shocks can impact company profitability. At times when major announcements hit the market, stocks of companies can drop".

Several respondents highlighted how cobalt's high price, together with other factors, had led to a desire to substitute it out of lithium-ion batteries. A cobalt trader (R32) noted, "…it seems that the future is all about nickel sulphate and high-nickel batteries". An integrated producer (R31) agreed that "…as a nickel and cobalt producer we are perfectly situated for the EV story. If they don't use cobalt, they will use more nickel". These respondents were making reference to the fact that lithium-ion cathodes are expected to evolve towards technologies that consume a higher loading of nickel and lower loading of cobalt. As an analyst (R2) explained:

"…cathode trends are driven mainly by Chinese subsidies which demand higher energy density, more power and more range. To get the subsidies you have to tick certain boxes and most of these boxes are

ticked, in cars at least, by cathodes with cobalt in them like NCM [nickel-cobalt-manganese] and NCA [nickel-cobalt-aluminium]. In the future, battery makers will try and get rid of cobalt in these cathodes because nickel offers high energy density. But as you know it's also because of the Congo issue, and of course cobalt's price. Nickel is much cheaper."

Chinese industrial policy was also put forward as a factor leading to more integration in the cobalt sector. One Chinese mine producer based in the DRC (R26) confirmed that "…owning cobalt mines here [in the DRC] is supported by the [Chinese] government. One trader (R10) mused that he suspects increased integration in the cobalt sector, between firms operating across China and the DRC, to be "…more to do with [the fact that] that country's [China's] aggressive industrial development plans…have nicely dovetailed with EVs – here the Government saw the opportunity and went for it". This comment suggests that Chinese producers have integrated in line with government industrial policy.

Based on the above research findings, there has been considerable integration in the cobalt supply chain in recent years and cobalt's criticality has been a contributing factor. Certainly, the consensus among interview respondents was that dialogue between different actors in the supply chain had increased over the past few years. As one integrated producer (R17) put it, "…all the big players want to talk to the miners now there is big demand". Such a view is supported by the results of the cobalt-sector survey. A total of 96% of respondents to survey question C4 agreed, or strongly agreed, that "…end-users (e.g. electronics/automotive OEMs) have become more involved with the procurement of the raw materials used to produce the refined cobalt products that they consume in recent years". Meanwhile, 79% of respondents to survey question C5 agreed, or strongly agreed, that "…mine producers have become increasingly more engaged with end users of cobalt in recent years. As one European automotive manufacturer (R18) commented, "…more people are talking more frequently to each other and some of them had never spoken to each other before. Communication is growing and consolidation is growing". The aforementioned integrated producer of cobalt (R17) explained why this was the case:

"Before, OEMs bought cobalt indirectly from the battery producer and didn't care about where the cobalt came from. Now they realise cobalt has a big risk and find that if they buy it from the battery producer, they cannot hedge the cobalt price, they have no plan B if there is a Congo supply shock, and they don't know where the cobalt comes from".

Several respondents spoke of a general change in awareness within the supply chain. One academic (R8) felt that "…awareness is being created in downstream industry about cobalt production and that is leading to vertical integration". This view was shared by a retired cobalt trader (R9):

"Where they have become more involved in direct investment and vertical integration I am not so sure but what I am sure of is that the OEMs have by necessity become more aware, partly to make it morally acceptable as you have to know where your stuff is coming from…even Apple, the car companies or Google have had people on the ground in Africa checking it out".

A closely related topic to vertical integration is industry consolidation. Economic theory suggests that most industries are initially fragmented but that they consolidate as they mature. The results of the cobalt-sector survey showed some support for the notion (survey question C7) that "…the cobalt supply chain has become more consolidated over the past ten years". A total of 60% of respondents agreed, or strongly agreed with this statement. Interviews with experienced industry actors suggested that consolidation has increased in recent years. One trader (R14) recalled that:

"Probably ten years ago, there were 30 to 40 refineries in China involved in the cobalt salts space. Now there are maybe ten major refiners so there definitely has been consolidation and that I that was maybe inevitable given that many of these company's setup without a business plan or source of material they just thought it would be an exciting industry to be involved in and they didn't think about the future".

An analyst (R1) also commented on Chinese consolidation saying that:

"…You have seen some consolidation by purchasing but some of them just closed down while the bigger ones have survived. I think Huayou's whole business plan is to try and knock everyone out by selling cheaper than production"

Several interview respondents discussed Huayou Cobalt's vertical integration and development as a lead firm in the cobalt sector. One Chinese depot worker in Kolwezi (R24) commented how "…the big Chinese companies dominate everything here. Mainly Huayou they are the biggest". A Director at a North American mining project (R13), highlighted how Huayou Cobalt had moved upstream and into the DRC:

"Huayou and other intermediaries invested in collection facilities to purchase hand-cobbed ores and concentrates from artisanal mines and small producers for shipment to a number of Chinese cobalt salt and oxide producers using atmospheric sulphuric acid and SX technologies. Chinese companies are more risk-averse and do not have concerns with investing in the DRC".

7.2.3 Summary

The preceding sub-chapter was concerned with RQ3 which asked: How have firms responded to perceived resource scarcity and demand growth? In particular, it sought to explore the hypothesis set out in Part I (chapter 3.5) that in response to cobalt's criticality, firms would have vertically integrated both forwards and backwards. RQ3 was set, and this subchapter intended, to help meet the broader research aim of understanding how firms have responded to cobalt's criticality, and how these responses have resulted in spatial and structural outcomes.

In terms of outcomes, research findings showed that the cobalt supply chain became increasingly integrated over the period under analysis. The Huayou Cobalt case study was used as an example of a lead firm having undertaken considerable forward and backward integration in a cobalt-sector setting. The important question that this dissertation asks is whether or not it is cobalt's criticality that has *caused* firms to integrate. Based on the responses of some firms, and some of the findings of this chapter, the answer is 'yes'. Certainly, the chapter has shown that concerns over supply risk have prompted firms to integrate backwards while demand for cobalt and its economic importance has prompted forwards integration and the pursuit of value capture through the production of higher-value products. However, these findings are not particularly unexpected. The various overlapping theories of firm structure (transaction cost theory, property rights theory, agency theory and resource-based theory) generally suggest that functions are brought inside the boundaries of the firm when there is a benefit in doing so. Backwards integration, to protect the cobalt raw supply line, and forwards integration, to create higher-value cobalt products, both make economic sense.

This raises the question of why some cobalt firms have vertically integrated and others have not? If there is an economic benefit to backwards integration, why haven't all refined cobalt producers undertaken this process? As is the case with FDI, one possible answer is that firms either lack the capacity or willingness to do so. For the most part, it has only been Chinese firms that have shown the desire to backwards integrate into the DRC (see section 7.1.2). Many others would not be willing to accept the economic benefits of doing so, because of the various risks associated (operational, reputational etc). In the conclusion of this dissertation the various motivations and enabling factors for integration (and FDI) are discussed further.

8. State responses to cobalt's criticality

The previous chapter examined firm-level responses to cobalt's criticality. This chapter turns its attention to the response of states. The cobalt-sector survey and subsequent interviews were designed in part to address RQ4 which asked: how have states responded to supply risk and economic importance? The hypotheses set out in Part I, was that resource-holding states will have undertaken resource nationalist approaches in order to capture value from the cobalt sector, while resource-seeking states will have created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value from the cobalt sector.

This chapter explores RQ4 and these two hypotheses through a focus on two case-study states, one resource-holding and one resource-seeking. The DRC is selected as the former, given that it has by far the world's largest cobalt reserves and resources, and is the largest mine producer of cobalt globally (USGS, 2016c). China is selected as the case study resource-seeking state as it is by far the world's biggest importer of unrefined cobalt and producer of refined cobalt. The selection of these countries as case studies also follows naturally from the firm-level analysis in chapter 7 which closely examined Chinese firms operating in the DRC.

8.1 China – a resource-seeking state

"Everyone is saying we should go to the western markets to scoop up [underpriced assets]. I think we should not go to America's Wall Street but should look more to places with natural and energy resources."

Chen Yuan, Chairman, China Development Bank, 2009

Despite being the world's largest producer of refined cobalt, China is not blessed with substantial cobalt reserves and resources. As such, China mines little cobalt itself and Chinese refineries have to source cobalt feedstock from abroad. As has been shown in the preceding analysis, the DRC is the principal source of China's cobalt feedstock. Part II showed how China imports vast amounts of unrefined cobalt each year, principally from the DRC. Importantly, over time, the nature of these imports evolved. At first, Chinese firms simply purchased cobalt from Congolese firms, or Western firms operating in the Congo. But over time, Chinese firms, backed by the Chinese state and Chinese banks, acquired numerous mines and processing facilities in the Congo. As shown in Chapter 7, Chinese firms have, over the past decade, undertaken considerable FDI in the DRC's copper and cobalt sectors to secure access to the raw materials they require. Having once been exclusively inter-firm trade, much of the cobalt units traded between the DRC and China today can be described as intra-firm trade.

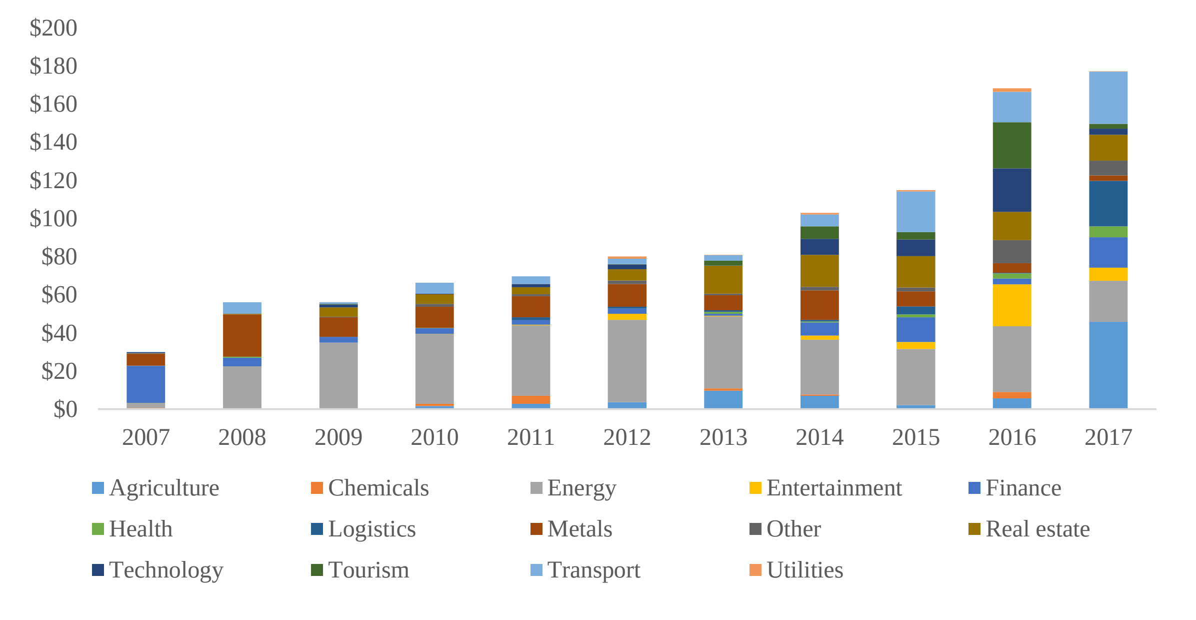
8.1.1 Chinese FDI in mineral assets

Chinese overseas investment in mineral assets has increased substantially over the last decade. In 2009, Beijing made public its intentions to use its sizeable foreign exchange reserves to acquire overseas assets. This was the first public admission of its policy to support corporations in buying offshore resources. In 2001, China has adopted the "Go Out (走出去)" policy to encourage Chinese enterprises to invest overseas (Shim, 2011). Initially, energy and mining assets were the central Chinese acquisition targets. During the first years of the "Go Out (走出去)" policy, numerous state-owned Chinese companies procured foreign natural resource companies (Shim, 2011). Between 2005 and 2010, China concluded 91 acquisition deals of overseas mining assets, with a total value of US$31.9Bn (Shim, 2011). Such acquisitions were supported through regulation. Indeed the *12th Five-Year Plan on National Economic and Social Development* specified that industry should prioritise "…international exploration and cooperation projects in important energy and natural resources such as oil and gas, iron ore, uranium, copper, and aluminium, and the building of long-term, stable, safe, and diversified multi-channel supply systems for natural resources" (State Council, 2011). Such acquisitions were also supported through credit. The Chinese government provided the SOEs with credit lines that facilitated their business development (Jansson, 2013). Support for Chinese companies developing their portfolios in African countries is provided mostly by China Development Bank or by China Exim Bank (Jansson, 2013).

Thus, the efforts of China's big businesses to go global can be thought of as being part of a national power-building globalisation strategy (Yao et al. 2010). Total Chinese FDI rose considerably after 2005 (Figure 45).

According to UNCTAD data, in 2012 China became the world's third-largest outward investor, with US$84Bn outward foreign direct investment flows, following the United States (US$329Bn) and Japan (US$123Bn) (Sauvant and Chen, 2014). While extractive enterprises remained a key target for overseas investment, Chinese actors (SOEs, as well as latterly private firms and funds) broadened their scope into other sectors. While this activity continues today, in 2013 China launched a policy of more structured, state-led investment in its near abroad: the Chinese government launched its *China Silk Road Economic Belt and the 21st-century Maritime Silk Road* development strategy, which aimed to economically link China with countries along the ancient Silk Road, and with others further afield through a new maritime network, through infrastructure investment.

Figure 45: China: Foreign direct investment, by sector, 2007 to 2017 (US$Bn)



Source: The American Enterprise Institute and The Heritage Foundation (2019)

China's regulatory framework is widely considered to be a key determinant of overseas investment (Buckley et al. 2008; Cui and Jiang, 2012; Luo, Xue, and Han, 2010). This framework seeks to facilitate and support FDI in order to nurture globally competitive Chinese firms by ensuring that these firms have a portfolio of locational assets which provide better access to markets and resources, making them more competitive (Sauvant and Chen, 2014). China's framework especially seeks to encourage FDI that can contribute most to the country's national development and it does this by selectively supporting particular industries and activities in their internationalisation through FDI (Sauvant and Chen, 2014).

With regard to extractive industries, FDI provides access to tangible and intangible resources that are of direct relevance to China's development effort (Sauvant and Chen, 2014). With regard to mineral extraction specifically, FDI enabled Chinese firms to strengthen the country's position in markets where it already had established mining and processing industries (such as nickel) through the acquisition of overseas assets. Further, FDI enabled China to get a foothold in markets for which it had limited economic geological resources. Metals and minerals could be mined overseas, by Chinese companies, or companies in which Chinese firms had invested, and the ores and concentrates produced could be shipped to China for processing. Thus, FDI enabled Chinese firms to benefit further economically from the upgrading of these materials and further still by their subsequent use in domestic industry and technology. By broadening the scope and geography of investment, China thus creates more options for economic (re-)structuring (e.g., value-chain upgrading and integration) and resource allocation optimisation (Sauvant and Chen, 2014).

There are various factors that can be said to influence decisions regarding *where* and *what* Chinese firms have invested in abroad. Numerous studies have suggested that natural resource endowment has been a major factor in determining the location of Chinese FDI (Buckley et al., 2007; Cheung and Qian, 2009; Elshamy, 2015; Wang and Yu, 2014), while others have found that natural resources have an insignificant impact (Kolstad and Wiig, 2009; Zhang, 2009). Of course, natural resource endowment is an essential determinant of FDI in the natural resource sector. A wide number of other factors have been argued to be crucial determinants of China's FDI, including institutional quality, market size, labour cost, location, and cultural similarity (Buckley et al., 2007; Cheung and Deichmann et al. 2003; Qian, 2009; Wang and Yu, 2014; Zhang, 2009). With regard to institutional quality, while some including Drysdale and Findlay (2009) have argued that strong institutions and governance attract FDI others such as Wang and Yu (2014) found that Chinese investment was driven to resource-abundant countries with poor institutional quality and governance.

8.1.2 Chinese FDI in African mineral assets

Chinese investment in sub-Saharan Africa can be traced back to the Conference of Non-Aligned Nations in 1955 (Brautigam, 2009; Konings, 2007). Kaplinsky and Morris (2009) characterise this as a first phase of Chinese investment into the region, when driven in part by ideological rivalry with the Soviet Union, China offered African states support, in some cases alongside military assistance and aid. Kaplinsky and Morris argue that the 1990s represents a second phase of Chinese involvement with sub-Saharan Africa, where after substantial growth in China's trade with Africa, and China's growing need for resources, large and predominantly state-owned enterprises entered the region as investors and implementers of aid projects (Kaplinsky and Morris, 2009). Thereafter, a third phase of Chinese interaction was one involving small and medium-sized predominantly private sector firms (Kaplinsky and Morris, 2009).

Generally speaking, Western firms investing in sub-Saharan have been funded directly or indirectly, through stock markets and a growing emphasis on 'shareholder value' over the past two decades has meant that this funding regime has had a short-term profit objective and has been very risk-averse (Kaplinsky and Morris, 2009). With the exception of small-scale copper mining smelters in Zambia and the DRC, virtually all of the resource-based Chinese investments in Africa were large in scale and involved Chinese SOEs (Kaplinsky and Morris, 2009). While, since 2009, SOEs have continued to dominate Chinese FDI in Africa, various factors including growing competition in China, the rise of production and labour costs, and a lack of financial support for individual entrepreneurs, has led to privately-owned Chinese enterprises seeking to penetrate the continent (Munalula and Kaliba, 2016). The copper and cobalt sectors were amongst the first that private Chinese firms invested in abroad and these private firms are much more like the risk-averse and short-term-profit oriented Western firms (Kaplinsky and Morris, 2009).

China often uses the strategy of engaging with African countries in development partnerships and as such, many countries on the continent have turned towards China for development support, giving China the opportunity for access to African resources (Munalula and Kaliba, 2016). China also provides aid for politically sensitive and prestigious projects, but these are often in economies where it has a direct resource interest and where seeks to build a long-term presence such as sports stadia in the DRC and Angola (Kaplinsky and Morris, 2009). Conversely, despite some exceptions, in general, there has been an unbundling of Western investment from aid and trade (Kaplinsky and Morris, 2009). Most incoming FDI from China has reflected a relatively tight bundling of investment with tied-aid, designed to facilitate the export of natural resources, predominantly directly to China (Kaplinsky and Morris, 2009).

8.1.3 Chinese FDI in the DRC cobalt sector

Chapter 7 detailed the considerable amounts of Chinese FDI in the DRC cobalt sector. A list of key Chinese investments/operations in DRC cobalt assets is also shown in Table 30. The nature of these investments varies considerably. Some represent simple investments in operational assets. For example, Metorex, a fully owned subsidiary of the Jinchuan Group, China, acquired Ruashi Mining and its Ruashi mine for US$1.1Bn in 2011. Other have been set up principally to source artisanally produce feedstock. For example, Congo DongFang International Mining, a subsidiary of China’s Huayou Cobalt is the largest single buyer of cobalt that originates from artisanal mines in and around Kolwezi (Amnesty, 2016).

Table 35: Chinese FDI in DRC cobalt assets			
	Company	Ownership	Assets
2005	Minière de Kalumbwe Myunga (MKM)	China National Overseas Engineering (China) (71%), Gécamines (DRC) (17.5%), EXACO (DRC) (11.5%)	Kalumbwe-Myunga
2005	Compagnie Minière de Musonoï (COMMUS)	China National Overseas Engineering (China), Gécamines (DRC)	Musonoï
2005	Feza Mining	Wanbao Resource (China) (51%), COMIDE (49%)	Kamoya
2006	CDM	Huayou Cobalt (China) (98%), Huayou Hong Kong (Hong Kong) (2%)	Kambove, Luiswishi, Mikas
2006	Compagnie Minière de Luisha (COMILU)	China National Overseas Engineering (China) (72%), Gécamines (DRC) (18%)	Luisha
2007	Sicomines	Chinese consortium (68%), Gécamines (32%)	Kolwezi
2007	Metal Mines	Han Rui (China)	Lakasi
2007	Congo International Mining Corporation (CIMCO)	China Railway Group (China) (51%), Earing Source Investment (China) (49%)	Luisha
2014	MJM	Jiayuan Cobalt (China) (100%)	-
2014	Huachin	China Nonferrous Metal Mining Group (China)	-
2017	Tenke Fungurume Mining	CMOC (China) (56%), BHR Partners (China) (24%), Gécamines (20%)	Tenke Fungurume

Source: Table 29, Table 30, Table 31

Note: Domiciles, start dates and ownership stakes are shown where available.

Another type of Chinese investment in the DRC has taken the form of resources-for-infrastructure deals. During, and in the aftermath of the Second Congo War, the DRC government had approved a large number of mining contracts which, based on the country's Mining Code, would eventually lead to profit- and production-based tax revenue (Carter Centre, 2017). However, directly after the election, President Kabila needed funds to implement his campaign promises (Carter Centre, 2017). Specifically, he needed to secure funding to implement *les cinq chantiers* (the five public works), improvements in infrastructure, health, education, water and electricity, and housing and employment (Jansson, 2013).

Recently signed mining contracts offered little revenue potential, as in 2006, most companies had not even started production, let alone become profitable (Carter Centre, 2017). Further, considerable international attention centred on the questionable transparency of some of the mining contracts signed, which pressurised the new Government into undertaking a strategic review of 61 mining contracts entered into between 1997 and 2003 (Kaplinsky and Morris, 2009).

It was in this context that the DRC government signed a US$9Bn 'minerals for infrastructure' deal in 2007. A Chinese consortium led by two major Chinese state-owned investors, China Railway Engineering Group (CREC) and Sinohydro, promised the DRC government loans of US$6Bn for infrastructure projects in exchange for the establishment of a joint venture company, *La Sino-Congolese des Mines* (Sicomines), with Gécamines that would operate copper-cobalt mines and use the profits to reimburse the loans (Carter Centre, 2017). As part of the deal, Congolese exploitation licenses 9681 and 9682 were allocated with Sicomines expected to invest about US$3Bn in a mining project (National Resource Governance Institute, 2017). In return, China committed to provide support for investment in infrastructure, power, education, and health with US$8.5Bn set to be allocated (Kaplinsky and Morris, 2009).

In order to expedite loan repayment, Sicomines was to be tax exempt until the loans were reimbursed, which required the development of a new "public-private partnership" law as this arrangement broke with the fixed-tax policy set out in the DRC Mining Code (Carter Centre, 2017). Loans were securitised by providing China with access to, and security provided by US$14Bn of copper and cobalt reserves (Kaplinsky and Morris, 2009).

The deal provoked considerable controversy. The IMF raised concerns that credit line was too large given the country's US$13.1Bn external bilateral and multilateral debt and argued that the value of the loans should be limited at US$ 3Bn (Jansson, 2013). Further, the IMF took issue with the fact that the Sicomines deal included a sovereign guarantee for the entire loan, meaning that the state would reimburse loans for both mining development and infrastructure should the profits from the mining venture proved insufficient to cover them (Jansson, 2013). Western donors had concerns that the Chinese government may burden the DRC government with US$9Bn of new debt, at a time in which the DRC was already heavily indebted and failing to pay existing donors (Jansson, 2013). Eventually, yielding to international pressures, the initial terms of the deal were altered so that the infrastructure element of the deal was capped at US$3Bn and the sovereign guarantee was removed.

Over a decade on, the Sicomines deal is still a source of controversy. Certainly, some infrastructure projects have been completed (Jansson, 2013) and the DRC government says the deal has already produced at least US$800M in infrastructure investment (Ross, 2015). However, there are concerns that loans have been partially wasted and that Sicomines acts outside the treasury. The Carter Centre

(2017) estimated that Sicomines received US$1.2Bn in loans between 2008 and 2014 to spend on infrastructure but distributed only US$478M. The Carter Centre (2017) found that:

The Sicomines loans do not transit through the state treasury, which will forego taxes for more than a decade. Instead, the loans arrive in bulk sums into the Sicomines account. Sicomines then disburses smaller sums for specific infrastructure projects. In other words, the joint venture operates like a financial platform that receives and disburses infrastructure money, comparable to a treasury that would receive and disburse tax money.

Questions also remain over how lucrative the deal has been, thus far, to the Chinese investors. A study by Landry (2018) found that the deal was less lucrative for the Chinese side between 2008 and 2016, largely due to a downward revaluation of the mine's estimated deposits, a downward spiral in copper and cobalt prices, and delays and setbacks that have plagued its operations.

8.1.4 The development of the Chinese cobalt sector

"China, unabashedly, wants to be the Detroit of electric vehicles."

Anthony Milewski, Pala Investments

While helping to strengthen the sector through encouraging and facilitating investment abroad, Chinese state action has also helped strengthen its domestic cobalt sector. In this regard, the State Reserve Bureau (SRB) has played a central role. China's SRB was formed in 1953, operates under the National Development and Reform Commission, and is responsible for planning, purchasing, storing, daily management of national strategic and relief materials (Cui and Ding, 2011). Its network spans the whole of China: as well as a national-level headquarters it has 22 provincial branches, four deputy bureau-level branches in Tianjin, Shanghai, Zhejiang and Shenzhen and 222 subordinate primary warehouses (Cui and Ding, 2011). Principally, the goal of the SRB is to acquire and manage strategic reserves of metals and other raw materials. The SRB has acted to stabilise and protect the domestic Chinese cobalt sector. At times of oversupply, the SRB has purchased cobalt from Chinese producers in order to stop prices falling significantly (Ritzema, 2015).

The Chinese government has more indirectly, but more significantly, supported its domestic cobalt firms through its recent policies related to electric vehicle (EV) subsidies. Given that EV batteries consume considerable quantities of cobalt, subsidies aimed at encouraging this fledgeling sector can be seen as hugely beneficial to Chinese (and ROW) cobalt producers.

To promote the market penetration of EVs, China launched the Electric Vehicle Subsidy Scheme (EVSS) in January 2009, followed by an update in September 2013 (Hao et al. 2014). Subsequent changes to China's EV subsidies were implemented in 2018. China has used various incentives such as R&D funding, lenient policies, and government procurement to push forward the EV development and specifically, EVs were outlined as the national strategic industry by the "*12th Five-Year Plan on National Economic and Social Development"* (Ou et al., 2017). Between 2009 and 2012, the government carried out the "Ten Cities - Thousand Vehicles" demonstration program which encouraged the sale of thousands of EVs in ten cities each year through monetary incentives and government procurement (Ou et al., 2017). Between 2013 and 2015, the central government extended incentives to all vehicle purchasers, including public fleets and individual buyers, while central ministries and provincial governments also carried out a series of incentives and policies for vehicles sales and OEMs to stimulate the growth of the market (Ou et al., 2017). The Purchase Tax Catalogue was issued in 2014 which exempted all the PEVs from the vehicle purchase tax (Ou et al., 2017). And in 2015, the government issued a financial subsidy plan with plans for the subsidies to be phased out over time (Ou et al., 2017).

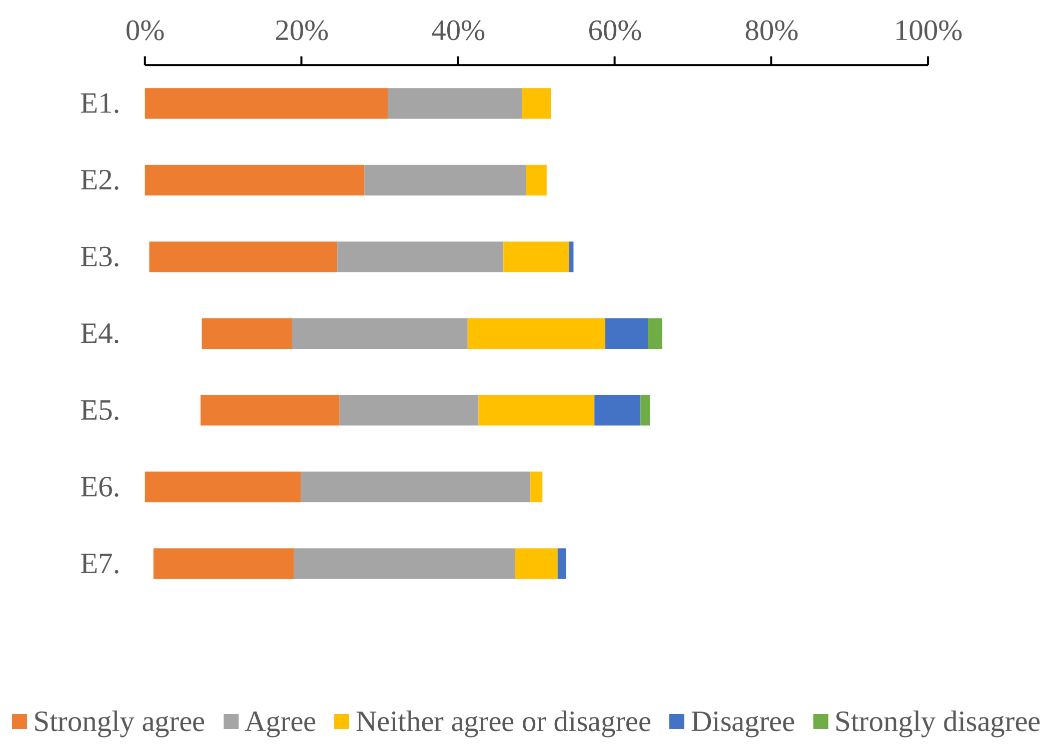
8.1.5 How has China responded to cobalt's supply risk and economic importance?

This subchapter sets out the research findings from the cobalt-sector survey and subsequent interviews with regard to answering RQ4: how have states responded to supply risk and economic importance? Table 36 shows survey respondents views on specific statements related to the Chinese states' role in the cobalt sector. These responses are charted in Figure 46 and Figure 47.

Table 36: Cobalt sector-survey results (Part E)

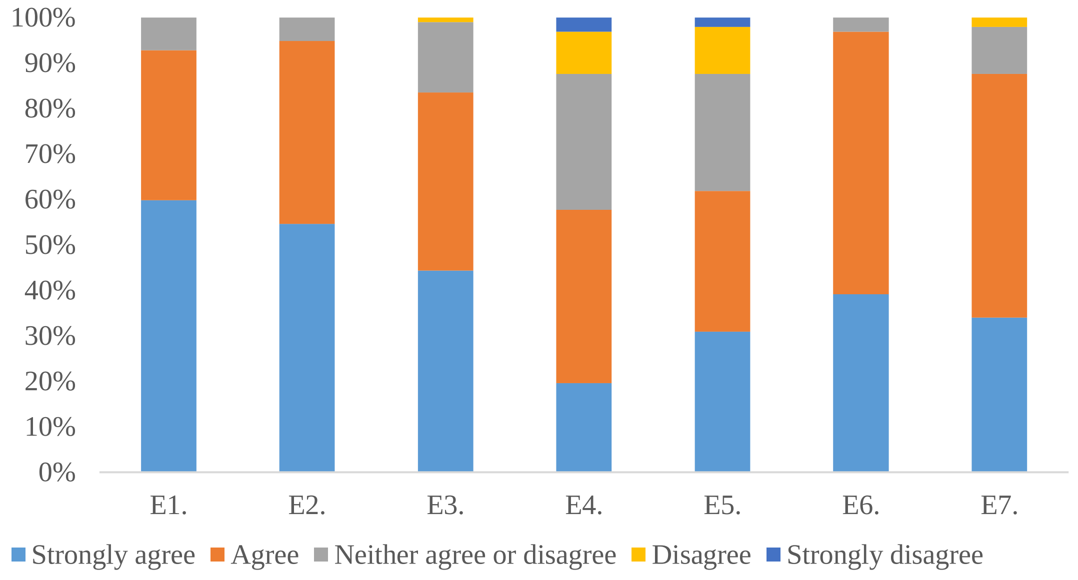
	Number of respondents					Statistical tests			
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree	n	t-test	p-value	Is the result significant at p< .10
E1. Demand for cobalt and its "economic importance" has led Chinese firms to aggressively acquire overseas mine assets	58	32	7	0	0	97	23.95	0.00001	Yes
E2. Chinese firms have invested heavily in the DRC in order to secure cobalt feedstock for Chinese refineries	52	39	6	0	0	97	24.78	0.00001	Yes
E3. Chinese investment in the DRC is actively encouraged by the Chinese Government	43	38	15	1	0	97	16.58	0.00001	Yes
E4. Chinese firms operating in the DRC are less likely to undertake socially and environmental responsible extraction	19	37	28	10	3	97	6.10	0.00001	Yes
E5. Chinese firms are more likely to source artisanally produced material than non-Chinese firms	30	30	24	11	2	97	7.30	0.00001	Yes
E6. Chinese control of DRC cobalt assets is likely to increase over the next ten years	38	55	4	0	0	97	24.78	0.00001	Yes
E7. Chinese end-users (e.g. electronics/automotive OEMS) have become more involved with the procurement of the raw materials used to produce the refined cobalt products that they consume in recent years	34	50	11	2	0	97	16.87	0.00001	Yes
Note: n=97 respondents									

Figure 46: Cobalt sector-survey results (Part E)



Note: 97 respondents

Figure 47: Cobalt sector-survey results (Part E)



Note: 97 respondents

A key aim of the research is to explore how cobalt's criticality, its economic importance and supply risk, have impacted state behaviours with regard to the cobalt sector. This sub-chapter looks to identify the drivers behind China's responses to cobalt's criticality, and motivations behind the significant investment in, and increasing control of, DRC cobalt assets. Research findings indicated strong support for the notion that "…demand for cobalt and its "economic importance" has led Chinese firms to acquire overseas mine assets (survey question E1)". A total of 93% of respondents to the cobalt-sector survey agreed, or strongly agreed, with this statement.

With more than half of all cobalt consumed in lithium-ion batteries, cobalt's economic importance is strongly connected to the portable electronics and increasingly the electric vehicle (EV) sectors. Several interview respondents noted that China's EV policy was an important reason behind Chinese foreign direct investment in cobalt assets. As one respondent, an academic focussed on sustainability and new technologies (R8) put it, "China wants to become a global industrial power and in EVs they have seen something on which they can capitalise". Several other interview respondents offered their views on the impetuses underpinning China's EV policy. Reducing dependence on oil, controlling pollution and furthering industrial development were recurring themes in interview discussions. An experienced cobalt trader (R9), outlined what he saw as China's three main motivations:

"China has been very specific from government downwards in terms of their motivation on a state basis, translated through to the various local enterprises by state encouragement and loans and directives and it's three-fold: to reduce their dependence on oil, keeping it's populous happy by reducing extreme pollution and to enable to play catch up, on an industrial basis, with the Western automotive sector. All of which falls into the general bracket of making China stronger and bigger and more important and economically and ultimately militarily more dominant".

Two other cobalt traders highlighted pollution and energy security as key aspects to China's EV strategy. The first (R17) noted that:

"China's five-year plans aim to develop EVs for two considerations. The first is pollution. The second is because if there are more cars on the roads, they will need more gasoline, and so to have less dependence on oil they need to find another way. EVs are important for both and to develop these they have to have copper and they have to have cobalt, so they encourage companies to secure it."

The second (R14) referenced pollution and oil dependence as well as personal enrichment as motivations for Chinese FDI in cobalt assets:

"Certainly, the EV industry has formed a central part of the Communist Party's strategy now for several years. On the face of it, it's to reduce the pollution issue. Secondly, it's to reduce the reliance on import of oil. Thirdly…and this is where I get a bit cynical…there may be a personal enrichment through industry…there is a story that the EV sector which is being designed to reduce pollution and to reduce the reliance on foreign oil actually will then enrich people very close to the political hierarchy in Beijing".

Certainly, interview respondents were in agreement that China's development of its EV supply chain has been centrally planned. An experienced industry player (R16) reasoned that the country's "…aggressive industrial development plans have nicely dovetailed with EVs – the government saw the opportunity and went for it". An academic (R8) suggested that the two main Chinese motivations underpinning FDI in the cobalt sector were "…economics and becoming a global power when it comes to EV production".

Undoubtedly, the development of China's EV supply chain, which requires huge amounts of cobalt, has been central to China's involvement in the cobalt sector, and the DRC. However, Chinese investment in the country's mining sector and its cobalt sector specially predates the commercial development of electric vehicles. The origins of China's activity in the Congo formed part of several interview discussions. One cobalt trader (R14) confirmed that "…growth in laptops and phones was the start. There was a suspicion [in China] that rechargeable batteries would grow. The Chinese are leading this and are five years ahead of the rest of the world". Several respondents noted that Chinese firms had been the first to realise the importance of Congolese cobalt. The CEO of a Canadian cobalt project (R13) noted that Western operators lagged behind their Chinese counterparts:

"Chinese investment in projects has been going on for the past 6-7 years but is only now being looked at by the broader investment community, by automotive and electronics OEM's trading companies and financial investors".

A cobalt trader (R9) confirmed that Chinese firms had been planning to acquire DRC cobalt assets for even longer, more than two decades. "How have they managed to do it? More than ten years ago, say 2003/2004, China was sending feelers out with metaphorical suitcases of cash with government saying, 'whatever it takes, get it'". Several respondents were quick to point out the importance of China's "Go Out (走出去)" policy to Chinese investment in DRC cobalt assets. As one cobalt trader (R17) said, "China is not only looking for cobalt – they want to secure companies and assets abroad for everything they need". The same trader mused that "Chinese banks and companies realise that high risk can bring high reward". Another respondent (R9) outlined how the policy has worked in practice:

"China has committed large dollars. The government at the top decides '…that's what we need'. They then fund it by telling local banks to go to local enterprises and say '…build a bigger factory' or '…here's some money, go and invest in buying a concession on the ground in Congo,' and they have encouraged the public floatation that a lot of these companies have done".

Such comments find support in responses to survey question E3 which asked whether "…Chinese investment in the DRC is actively encouraged by the Chinese Government". In total, 83% of respondents agreed or strongly agreed that this was the case. One interview respondent (R16) said this on the subject:

"The Chinese government has gone all out for raw materials. They've had a very dynamic plan and put billions into the DRC on the basis that they provide it with infrastructural development and investment while acquiring rights to raw materials. The government has done more than anyone else to look after the raw materials demand in their own markets".

Another interview respondent (R5), an employee of a refined cobalt producer in China, also suggested that there were tax incentives in place to support Chinese cobalt importers that had an investment in the Congo. They said:

"…one way the Chinese government helps firms is through taxation. Importers of ores and concentrates would normally have to pay an import tax. But if the company exports a small proportion of the refined material they produce, they can avoid the tax".

These comments about central planning and incentives, together with the results of survey question E3 suggest that China has purposefully created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities. With regard to the development of its domestic sector specifically, responses to the cobalt sector survey showed strong support for the notion that Chinese firms have invested heavily in the DRC in order to secure cobalt feedstock for Chinese refineries (survey question E2). A total of 94% of respondents strongly agreed or agreed with this statement. As one European automotive producer noted (R18):

"I am impressed with how China has strategically localised the whole battery industry in China, or at least Asia – both batteries and raw materials. The rest of the world cannot get around China anymore because of its huge plans to create leadership of the EV industry in China through investment in places like Africa".

As noted above, a key consideration in the interview and survey design was to examine whether cobalt's criticality, its economic importance and supply risk, were key motivations behind China's investment in the DRC cobalt sector. The findings outlined so far in this sub-chapter confirm how cobalt's economic importance was certainly a principal consideration. Supply risk, too, was considered to be a key factor. When asked to identify the main motivation for Chinese FDI in cobalt assets, a respondent from a leading global automotive firm (R6) said simply, "…security of supply all the way. Period." Other respondents echoed this sentiment. One academic (R7) noted that "…we see raw material supply mostly redirected into China through offtake but increasingly through investment – especially if they lack the geology to mine it themselves". One Chinese mine CEO in the Congo (R27) put it simply:

"China has most of the world's cobalt refineries and almost none of the world's cobalt mines. If we don't invest and mine abroad, it is simple, we may end up with no cobalt to process. It could be diverted to America, or Europe, or Japan. So, there is a supply risk. A risk that our refineries would have no supply".

Chinese investment in the DRC has led to its firms controlling more DRC assets than firms from any other jurisdiction (including the DRC itself). As one mine developer (R15) commented, "China has the refined capacity at home and now a stranglehold on a lot of DRC mine production". Indeed, many respondents foresaw Chinese influence in the Congo increasing. Survey question E6 asked whether Chinese control of DRC cobalt assets is likely to increase over the next ten years. A total of 96% of respondents to the cobalt-sector survey agreed, or strongly agreed, with this statement. One financer with interests in cobalt equities (R4) reasoned that:

"China now dominates DRC cobalt and copper. China doesn't require the same conditions as western donors when they invest. They build roads and schools if needed, in return for mining rights. There are not many strings attached. Of course, it's up to the Congolese executive but unless they want to kick the Chinese out, they will continue to dominate mining in the Congo".

This comparison with Western investors and firms was made by several other interview respondents. One UK broadsheet journalist (R12) noted, that China is keen to cultivate relationships outside of a Western sphere of influence:

"Improving the political relationship with the DRC [is a key motivation of China's]. Africa has resources and markets that they [China] want so China wants to have good relations especially with countries the West don't have strong relations with".

The nature of relationship underpinning of Sino-Congolese relations was another recurring theme in interviews. As per the previous quotation, some respondents commented on government-level relations. One analyst (R2) called the situation a “marriage of convenience” and another (R1) a “mutually beneficial supply and demand relationship – one supplies cobalt the other supplies money”.

At a state level, it is clear that relationships have been highly positive at times. Chinese firms have invested billions of dollars into the DRC. Nonetheless, recent changes to the DRC mining code appears to have soured relations since 2017.

At a more local level, interviews in Lubumbashi and Kolwezi suggested that relations between the Chinese and Congolese were also mixed. A businessman developing a sustainable artisanal project in Kolwezi (R23) noted that “…the Chinese don’t want to invest in artisanal projects that belong to the Congolese”. His contention was that Chinese financiers and miners were only interested in extracting value, not investing in local communities of the long term. “They don’t want long term collaboration. They just want cobalt. They don’t support the local economy”. This was partially reinforced by an executive at a Chinese mining firm operating in the Congo (R27) who mentioned how her employer imports everything they need from China: “We import most of the materials to use in Kolwezi from China, including materials for industry and for the workforce”.

Aside from investment in the DRC, several interview respondents also cited recycling as an important Chinese response to cobalt’s criticality. An analyst (R2) stated that “…China have invested a lot into recycling with firms like GEM and Huayou Cobalt said to recover thousands of tonnes each year”. Another analyst (R3) said that “…these batteries are incredibly valuable at certain times, depending on the price of lithium, cobalt, nickel etc. The future economics of recycling are hard to work out, but it’s likely that cobalt recycling will be a feature of the market in the future, especially if prices are high”. However, one trader (R14) argued that current recycling levels are overstated, saying that “…having been to these places it doesn’t look like the facilities are used much. It doesn’t make sense that huge volumes are being recycled now. Maybe it sounds good [for firms] to say it”. These responses suggest that Chinese firms are exploring other avenues, as well as investment in the DRC, to obtain future access to cobalt units.

8.1.6 Summary

The preceding subchapter was concerned with RQ4 which asked: how have states responded to supply risk and economic importance? In particular it sought to explore the hypothesis set out in Part I (chapter 3.5) that resource-seeking states would have created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value from the cobalt sector. It did so through a focus on China, by far the most important resource-seeking state in the cobalt supply chain. RQ4 was set, and this subchapter was intended, to help meet the broader research aim of understanding how states have responded to cobalt's criticality, and how these responses have resulted in spatial and structural outcomes.

Central to this dissertation is the question of whether criticality a causal dynamic. Has it shaped the structure and geographies of supply chains? Research findings show that cobalt's criticality has led to a concerted effort on the part of China to gain control of the DRC cobalt sector. Cobalt's economic importance, especially to the EV sector but also to electronics and other sectors, makes access to it of vital importance to the Chinese economy. And its supply risk, a result in particular of the high concentration of production in the DRC, means that Chinese actors have worked hard to ensure access to cobalt units through investment.

As discussed in detail in chapter 7, Chinese firms have engaged in considerable FDI in upstream DRC copper and cobalt assets. There are a large number of justifications for doing so. Potential determinants for FDI include a motivation to achieve higher returns in foreign markets through lower labour costs and exchange risks; ownership benefits, economies of scale and incentives; and oligopolistic and behavioural drivers based on following competitors into foreign markets (Assunção, et al. (2011). As set out in the summary of chapter 7 (chapter 7.1.3), Chinese FDI in the DRC fits neatly with Dunning's (1988) "ownership, location, and internalisation (OLI)" approach, which suggests that three advantages that can underpin a firm's decision to become multi-national. GPN literature articulates FDI as a form of strategic coupling, a "…mutually dependent and constitutive process involving shared interests and cooperation between two or more groups of actors who otherwise might not act in tandem for a common strategic objective" (Yeung, 2009: 332). This also fits neatly with the Chinese case study.

The findings of this chapter support the hypothesis that the Chinese state has created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value. Acquisition of DRC cobalt assets has been made possible and indirectly encouraged by various policies and strategies. First, China's "Go Out (走出去)" policy encouraged Chinese enterprises to invest overseas, especially in mining and energy assets. Second, the regulatory framework in China seeks to facilitate and support FDI in order to nurture globally competitive Chinese firms by ensuring that these firms have a portfolio of locational assets which provide better access to markets. Third, China's "12th Five-Year Plan on National Economic and Social Development" outlines EVs as a national strategic industry supported by various subsidy and incentive schemes. The DRC's cobalt sector represents an ideal investment destination for China. Cobalt (of which China has negligible domestic resources) is essential to make China's EV strategy a reality and, unlike other resource-holding states, the DRC is a preferable candidate for Chinese investment from private firms and SOEs; a country with rich mineral resources, in need of infrastructure development, and with limited relations with Western donors.

In combination, these findings represent the key contribution of this sub-chapter which is to show how state-level dynamics and policies are central factors which have enabled FDI and vertical integration in a cobalt-sector context. The chapter also serves to highlight that firms such as Huayou Cobalt are not the typical lead firms of the GPN literature. These points will be revisited and discussed further in the dissertation's conclusion.

8.2 The DRC – a resource-holding state

As noted above, the cobalt-sector survey and subsequent interviews were designed to address RQ4 which asked: how have states responded to supply risk and economic importance? The hypothesis, set out in Part I, was that resource-holding states such as the DRC will have undertaken resource nationalist approaches in order to capture value from the cobalt sector, while resource-seeking states like China will have created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value from the cobalt sector.

This sub-chapter turns attention on the Congolese state. The preceding analysis has already emphasised the importance of the DRC to the cobalt sector. The DRC has by far the world's largest cobalt reserves, 49% of the global total (USGS, 2016c). Chapter 5 showed how the country's enormous mineral reserves have made it the world's largest mine producer of cobalt, and chapter 6 set out how the DRC exports vast amounts of unrefined cobalt each year, principally to China.

Chapter 7 showed how since the early 2000s, numerous overseas firms have undertaken FDI in the DRC's cobalt sector. The chapter outlined how the introduction of a new mining code in 2002 paved the way for this influx of investment yet also effectively placed control of the mining sector into the hands of Gécamines, a state-owned enterprise. Below, this sub-chapter first examines recent changes to the DRC mining code before exploring other examples of resource nationalism.

8.2.1 The DRC mining code revision

The purpose of the 2002 mining code was to enact a comprehensive set of rules covering not only the definition, acquisition, operation and termination of mining rights but also issues related to mining such as environment protection, cultural heritage, marketing and transport of ore, pledges and mortgages, health and safety, tax incentives and customs duties, currency exchange, special guarantees from the state, force majeure, construction of infrastructure, sanctions for breaches and dispute resolution (Hubert, 2007). With regard to cobalt and copper, royalties were set at 2% and 2.5% respectively.

In 2018, the DRC adopted a new mining code. DRC law n°18/001 of reforming the Mining Code (MC), was assented to by the President in March 2018 and published in the Official Gazette later that month (EY, 2018). The scale of mining royalty was increased from 0% to 6% depending on the type of mineral and raised to 10% for strategic minerals as determined by the Government (EY, 2018). Cobalt royalties were initially set at 3%, while copper royalties were raised from 2.5% to 3.5%. Cobalt royalties were increased to 10% in December 2018 as the metal was classified as strategic. Thus, mining code changes dramatically increased cobalt royalty payments to the DRC state.

Several other stipulations of the mining code further strengthened the state's control of the sector and boosted government coffers (Finan, 2018). First, the state's free-carry shareholding in mining companies was increased from 5% to 10%, and by a further 5% each time a permit is renewed. This increased the state's ownership of mining companies operating in the DRC, and further increase it over time. Second, access to a documented state-studied deposit, secured by tender, became subject to the payment to the state of 1% of the price paid for the tendered deposit. Third, a 'super profits' tax of 50% was introduced on profits exceeding 25% of those forecast in the mine feasibility study. Fourth, requirements relating to state approvals for transfers were expanded, including a new requirement that changes-of-control (including certain share transfers) in companies holding a mining permit is subject to state approval.

Mining code changes prompted criticism from major mining companies operating in the country including Glencore, Randgold, Ivanhoe Mines, MMG and China Molybdenum who unsuccessfully lobbied the government to respect the terms of the so-called "stability clause" in the 2002 charter, which granted mining companies immunity from any changes to the mining code for a period of 10 years after implementation (Yeomans, 2018).

Other changes to the Mining Code appear more geared towards sustainability than value capture (Finan, 2018). For example, new rules required mining companies to contribute a minimum of 0.3% of turnover to development projects for communities affected by the mine's activities, and 10% of royalty payments must now be paid to a fund dedicated to future generations. Other stipulations mandate more beneficiation of raw materials in country, as well as better safety. New rules make the export of raw minerals forbidden and mining permit holders must now present a plan for the refinement of their minerals to the mining authorities. Further, mining companies must now establish a provision of 0.5% of turnover for mine rehabilitation.

8.2.2 Resource nationalism – the case of FQM

The DRC's revision of its mining code and the creation of a new set of rules which boost state control of the sector as well as government coffers can be described as a form of resource nationalism. The term 'resource nationalism' refers to various forms of state involvement in the extraction, processing and sale of natural resources (Pryke, 2017). Another definition sees it as anti-competitive behaviour designed to restrict the international supply of a natural resource (HMHSP, 2014). The term can thus encompass nationalisation and expropriation of foreign companies, export restrictions, cartel pricing behaviour or high taxation (HMHSP, 2014).

As Pryke (2017) notes, the incentive for resource nationalism is accentuated when prices are high or when the amount of compensation a seller may receive for an asset is high. The same is true when demand (for a mineral deposit or commodity) is high. It has also been argued that supply shortage increases the incentive for resource nationalism and that resource nationalism is to be expected in an environment of supply disruptions, volatile prices, accelerated environmental degradation and rising political tensions over resource access (Lee et al. 2012).

The case of First Quantum Minerals (FQM) and its DRC cobalt assets is one of expropriation of a foreign company's asset. FQM, a Canadian mining company, discovered the Frontier copper-cobalt deposit in the DRC in 2004 and reached commercial production in 2007 (FQM, 2018). Later, in 2006, FQM acquired Adastra Minerals which owned the Kolwezi copper-cobalt project (FQM, 2018). Through deals with the DRC government and Gécamines, the company thus held stakes in two promising assets. In the case of Frontier, the DRC state held a 5% stake as mandated in the Mining Code, which stipulated that a company had to concede a stake to the DRC when it transformed its research permit into an exploitation permit (Carter Centre, 2017). FQM, together with the World Bank's International Finance Corporation, spent US$750M developing the Kolwezi project (MacNamara and Thompson, 2010).

In September 2009, the DRC government seized the Kolwezi project site, citing contract violations (MacNamara and Thompson, 2010). In 2010, the government also nationalised the Frontier mine and suggested that it would investigate First Quantum Minerals for "suspected wide-scale misconduct" (MacNamara and Thompson, 2010). Ownership of the mine subsequently passed to Sodimico, a state-owned enterprise, after the DRC's Supreme Court decided in May 2010 that FQM illegally obtained the rights to the concessions (Roskill, 2018). The DRC Supreme Court ruling was that FQM had been granted prospecting rights over Frontier but not explicit mining rights (MacNamara and Thompson, 2010).

In response, FQM suspended construction of the Kolwezi project in September 2009 and initiated international arbitration proceedings against the government (FQM, 2018). In August 2010, the company shut down operations at the Frontier mine and initiated further international arbitration proceedings against the government (FQM, 2018). Meanwhile, Sodimico sold its share in the two projects, reportedly for significantly less than market value (Roskill, 2018). In August 2011, Reuters and Bloomberg reported that Sodimico had sold its share in the two copper-cobalt projects for US$30M – just 6% of the estimated value of the stakes, according to analysts – to two companies associated with Dan Gertler in March 2011, and that the proceeds of the sale were used in part to contribute to an election fund (Global Witness, 2016). Sodimico' s stakes were sold to two Gertler-linked BVI companies called Sandro Resources Limited and Garetto Holdings Limited (Global Witness, 2016).

Action has been taken against the companies involved in the scandal. Following its acquisition of the Kolwezi mining project, ENRC became embroiled in a long-running dispute with FQM and in January 2012 ENRC agreed to pay US$1.25Bn to FQM to settle the matter (Global Witness, 2016).

Until their cancellation in 2009 and 2010, FQM's projects Kolwezi tailings and Frontier projects were the type of successful investments that the mining code aimed to attract (Carter Centre, 2017). However, as one interview respondent put it:

"The Frontier debacle is a clear example of the government having a preferred partner that would give them more cash in return for access. They [the DRC government and Gécamines] do this all the time under the radar but in this case they went as far as to strip a big-name mining company of its assets."

8.2.3 Resource nationalism – an export ban

Another example of resource nationalism in the DRC relates to a proposed ban on the export of its copper and cobalt. The DRC has frequently threatened the cobalt market with a ban on the export of unprocessed copper and cobalt ores and concentrates. In 2013, the DRC government went so far as to announce a ban on the export of copper and cobalt concentrates to encourage miners to process and refine metal within its borders (Hogg, 2013). The DRC had attempted to introduce similar rules in 2007 and again in 2010, but each time the decision was reversed (Hogg, 2013). Indeed, the 2013 ban never came into force, with the government proclaiming that the proposed ban would be pushed back and instead heightened taxes on cobalt concentrate exports were put in place. The ban was further delayed in 2015 and then 2016 and as of 2019, the ban remains on-hold. While in principle, such a move could be used to stimulate more production of higher-value refined cobalt in the DRC, the country lacks the processing capacity and associated infrastructure to achieve this without considerable investment.

8.2.4 How has the DRC responded to cobalt's supply risk and economic importance?

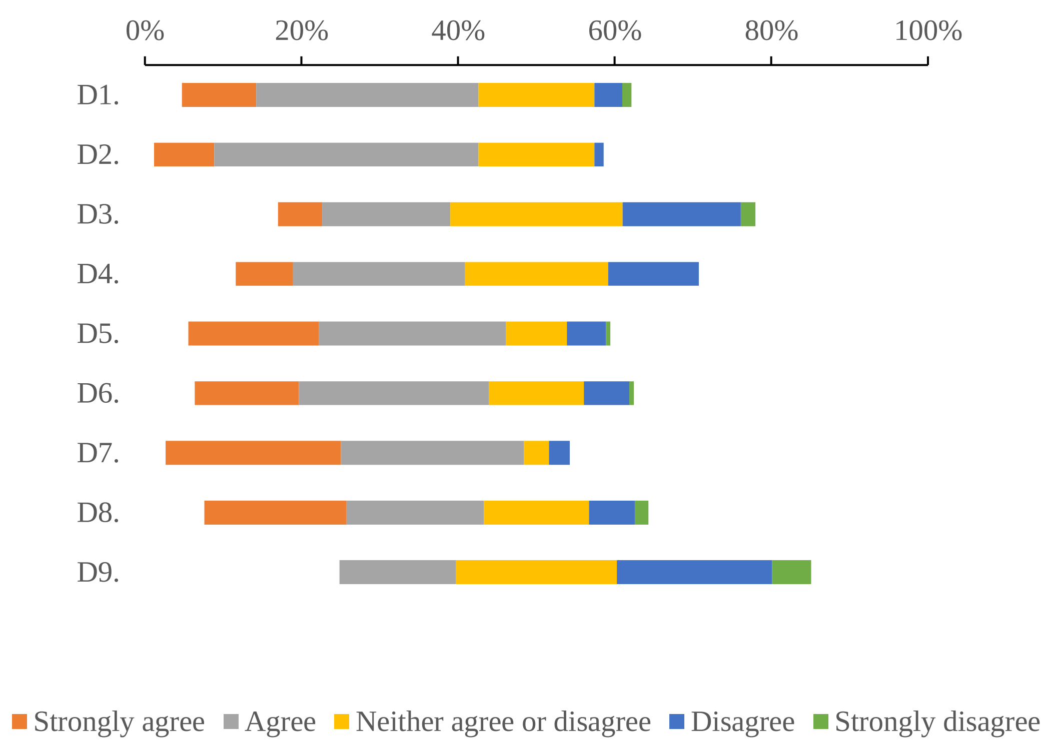
This subchapter sets out the research findings from the cobalt-sector survey and subsequent interviews with regard to answering RQ4: how have states responded to supply risk and economic importance? Table 37 shows survey respondents views on specific statements related to the DRC states' role in the cobalt sector. These responses are charted in Figure 48 and Figure 49.

Table 37: Cobalt sector-survey results (Part D)

	Number of respondents					Statistical tests			
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree	n	t-test	p-value	Is the result significant at p< 10
D1. The DRC uses the threat of resource nationalism to maximise its revenues from its mining sector	16	47	26	6	2	97	23.95	0.00001	Yes
D2. The DRC uses the threat of resource nationalism to exercise control over foreign firms operating in its jurisdiction	13	56	25	3	0	97	24.78	0.00001	Yes
D3. The DRC Government is likely to introduce an export ban on unrefined cobalt over the next ten years	9	27	33	25	3	97	16.58	0.00001	Yes
D4. The DRC Government has been selective about which firms acquire or invest in its cobalt assets	12	37	29	19	0	97	6.10	0.00001	Yes
D5. Demand for cobalt and its "economic importance" has prompted the DRC Government to change its mining code	31	44	12	9	1	97	7.30	0.00001	Yes
D6. The revision of the DRC mining code is intended to increase the level of state control over its mining sector and mining titles	23	42	21	10	1	97	24.78	0.00001	Yes
D7. The revision of the DRC mining code is intended to increase state revenues from the mining sector	42	42	8	5	0	97	16.87	0.00001	Yes
D8. The revision of the DRC mining code makes the country less attractive for foreign direct investment	31	30	23	10	3	97	23.95	0.00001	Yes
D9. The revision of the DRC mining code is intended to improve the social and environmental responsibility of mining companies operating in the country	0	24	33	31	9	97	24.78	0.00001	Yes

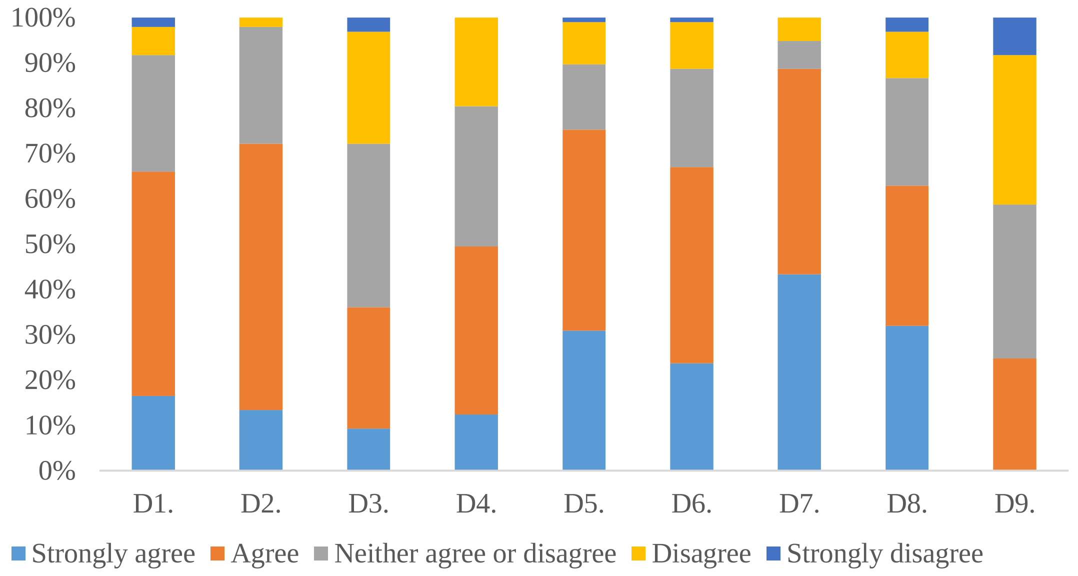
Note: n=97 respondents

Figure 48: Cobalt sector-survey results (Part D)



Note: 97 respondents

Figure 49: Cobalt sector-survey results (Part D)



Note: 97 respondents

A key aim of the research, and the main focus of Part III, is to explore how cobalt's criticality, its economic importance and supply risk, has impacted state behaviours. This sub-chapter looks to identify the drivers behind the DRC's responses to cobalt's criticality. The hypothesis, set out in Part I, was that resource-holding states such as the DRC will have undertaken resource nationalist approaches in order to capture value from the cobalt sector.

Changes to the DRC's mining code, as outlined above, are an example of resource nationalism. Several interview respondents were happy to label changes to the mining code as such. As one analyst (R2) said, "…yes it's [changes to the mining code] a form of resource nationalism for sure. They [the government] have changed the rules to make themselves more money. It's quite simple". Section D of the cobalt-sector survey focussed considerably on the motivations behind recent changes to the DRC's mining code. Survey results showed strong support for the notion that cobalt's criticality had a role to play in the implementation of new regulations. A total of 77% of respondents agreed, or strongly agreed, that "…demand for cobalt and its "economic importance" has prompted the DRC Government to change its mining code" (survey question D5).

Several interview respondents confirmed that cobalt's economic importance, concerns about its availability, recent high prices, and the bullish outlook for demand, had resulted in DRC state action and prompted a change in the mining code. An integrated cobalt producer with operations in Africa (R17) noted that:

"High cobalt prices put more attention on the material, so the DRC government changed its attitude, became more strict, and wants more benefit. Higher taxes, and more expenses will be required in the future. Gécamines will become more greedy the more interest there is in cobalt".

A retired cobalt trader (R9) made a similar point, highlighting how cobalt's criticality, and its economic importance, in particular, has made the Congolese authorities aware of the sway they hold over the market:

"The powers that be in Congo have realised, in the case of cobalt, that they are more and more in the saddle and in the driving seat to almost hold to ransom the Western companies for this critical element thanks to the electric vehicle revolution. There is an awareness of that, and that awareness is expressing itself in some of the mining codes etc."

The suggestion of '…holding the West to ransom' relates to the high concentration of cobalt production in the country, the key factor underpinning cobalt's supply risk in criticality studies. Several other interview respondents agreed that supply risk had shaped the behaviour of the DRC, a resource-holding state, as well as resource-seeking states like China. The CEO of a cobalt mine project in North America (R13) commented that "…the Congolese authorities are well are of concerns around security of supply and its factored into how they deal with miners". An industry pricing specialist (R11) went as far as to say that "…promoting a narrative of supply risk probably suits the powers that be [in the DRC]. If there were not concerns about supply risk, there probably wouldn't be so much investment in African cobalt mines".

The cobalt-sector survey explored resource nationalism and the DRC mining code across several questions, designed to gather respondents' opinions on *why* the new code was introduced. The exercising of more power or control was a common theme. In total, 72% of respondents to the cobalt-sector survey agreed, or strongly agreed that "…the DRC uses the threat of resource nationalism to exercise control over foreign firms operating in its jurisdiction (survey question D2). Furthermore, 67% of respondents agreed, or strongly agreed that the "…revision of the DRC mining code is intended to increase the level of state control over its mining sector and mining titles (survey question D6).

The previous chapter outlined the significant powers held by Gécamines and its control over cobalt assets. As one automotive producer (R6) put it, "Gécamines is such a force without really even producing cobalt". One cobalt trader (R14) confirmed the fact outlined above that Gécamines power is unjustified yet codified, suggesting that "…the ownership that Gécamines gets in these projects is in return for nothing. You literally have to hand over a share of your project to avoid getting legal complaint". The same trader elaborated that Gécamines was guilty of chronic mismanagement as well as corruption:

"Gécamines is still the holder of the richest and largest selection of mining permits in Congo. With a bit of money, they could pick the richest one, start exploiting it and use than the revenues from that to exploit others but it's total mismanagement and corruption on an industrial scale".

A retired cobalt trader (R9) made the direct link between Gécamines and corruption:

"You only have to look at the Dan Gertler type deals – tens-of-millions of dollars were exchanging hands in return for mining licenses that were going sideways either to Switzerland or into private election funding".[1]

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[1] Forbes (2019) notes that Dan Gertler built a fortune through mining ventures in Africa, primarily in the DRC; sold his stake in two mines in the Congo to Glencore for US$96M making an estimated

Power and control were, thus, found to be key motivations behind changes to the DRC mining code. However, increasing revenues was the most widely referenced motivation. Of all the statements related to the mining code in the cobalt-sector survey, that which resonated most with interview respondents was that "…the revision of the DRC mining code is intended to increase state revenues from the mining sector" (survey question D7). A total of 84% of respondents agreed, or strongly agreed, with this statement. The new code and associated policies saw cobalt classified as a 'strategic metal' and royalties on it rise to 10%. As one cobalt trader (R14) put it, "I think the whole trying to say that cobalt is strategic material and changing the royalty to 10% was nothing other than a money grab".

Most interview respondents reasoned that the key reason for the mining code changes, and the key motivation of the DRC government with regard to cobalt, was to maximise state revenue. One analyst (R1) argued that "…it's [the state's aim] to increase as much revenue that they can get from cobalt as possible. It's not to develop a sustainable, long term mining industry". An automotive producer (R6) agreed, suggesting that "…from the state's point of view, it's all about increasing income for what comes out of the Congo via tax revenue".

During interviews, respondents mentioned other types of resource nationalism that the DRC state could be said to have undertaken. Few cobalt-sector survey respondents thought that "…the DRC government is likely to introduce an export ban on unrefined cobalt over the next ten years (survey question D3). Indeed, only 37% of respondents agreed, or strongly agreed with this statement while 34% neither agreed nor disagreed. Nonetheless, the export ban was a recurring theme in interviews. One analyst said that (R3) "…the export ban talk is really just a warning shot to the market. A reminder that even though taxes are high etc. things could be worse". Another analyst (R1) mused that "…the ban would probably never happen and in the past, I think things ended up with just a tax rise, but really the threat of the ban is just as effective". This resonates with the findings of survey question D1, which asked whether "…the DRC uses the threat of resource nationalism to maximise its revenues from its mining sector". A total of 63% of respondents to the cobalt-sector survey agreed, or strongly agreed, with this statement. As one cobalt trader put it (R10) "…The First Quantum affair [see chapter 8.2.2] remains in the collective memory of the market. Miners know that they can get away with murder in Congo. But they also know that ultimately, the state can take everything away overnight".

US$400M; was placed on a US sanctions list for his alleged corrupt business deals in the Congo by the in 2017; and had US sanctions levied against 14 additional companies including Fleurette Africa Resources and Ventora Development in 2018.

It is clear from the findings of interviews that most sector participants see the maximisation of revenues from the cobalt sector as the main motivation of the DRC government. While most respondents talked negatively about state efforts to maximise revenue, others spoke more positively about state efforts to capture more value from its mining sector. As one Zambian geologist working in the Copperbelt argued, "…the government is trying to capture more value. We currently mine copper, export it for refining, and buy back copper wire for even more money. Same with cobalt". It is clear that there is a desire to beneficiate more cobalt and copper in the DRC. However, a lack of investment in the sector, and in associated infrastructure, makes this impossible. As a European automotive producer (R6) pointed out:

"I know from being there that they were always pushing for cobalt metal to be produced there, and Glencore came up with a plan to produce metal, but at the end of the day you don't have a stable grid. You can't have cathode hanging in solution and the power goes out".

A logistics provider in the DRC (R21), however, suggested that the power supply was sufficient for extractive and processing operations, just not for the local population. He said that "the power is OK in Kolwezi because of the mining. But outside of the city people only get power every other day". Nonetheless, other interview respondents described the possibility of more cobalt in the DRC as "impossible at present" (R11) and "only possible on a very small scale, which is probably not cost competitive (R1). One automotive producer, who had travelled and worked in the DRC extensively (R6), predicted that "…when I am dead and buried there will probably be metal going from Congo to refineries everywhere but that's going to take a long, long time". Other types of infrastructure were cited as an issue too. A South African exploration geologist working in the DRC (R19) commented that "…there are not many sealed roads. The rains have a big impact on the cobalt sector as they effect exploration, mining and trucking". Ultimately consensus from interviews was that infrastructure left DRC producers with little choice than focus on the production and export of unrefined cobalt products; cobalt ores and concentrates and cobalt intermediates. As the aforementioned automotive producer (R19) reasoned:

"The hydroxide and carbonate I think is the balance between what is practical on the ground there with reagents and electricity but there is no doubt that the Congo state will continue to put pressure on the big guys to produce metal or to increase their value added".

While value-capture was widely cited as a key motivation behind DRC state involvement in its cobalt sector, most interview respondents were quick to point out that much of this value is lost to corruption. One academic (R8) argued that the "…DRC state is more about government interest and economic interest than addressing issues of poverty or making sure that there is fairness in the system or responsible business practices". The cobalt-sector survey findings certainly suggest that the mining code changes were not aimed at fairness or sustainability. No interview respondents strongly agreed that "the revision of the DRC mining code is intended to improve the social and environmental responsibility of mining companies operating in the country" (survey question D9). Only 25% agreed with this statement. Instead, corruption and value capture were widely discussed issues across most interviews undertaken. A retired cobalt trader (R9) gave this assessment:

"I am assuming that there is somewhere a desire to heave the country up by its own bootstraps and reap the benefits of some of its mineral resources that have been exported for decades and for generations to the benefit of the initially the colonialists and the Belgians and then the private businesses – but to say that there is a unified, domestic government motivation to improve the country in Congo would be giving it too much credit. But if it is there, it is so obfuscated in greed, corruption, political infighting, and tribal warfare"

Meanwhile, one experienced industry player (R16) gave the following, damning assessment:

"Unfortunately, the DRC government is just a fool to itself, a fundamentally corrupt government. I wouldn't credit it with doing anything proactive apart from stealing money, it's very greedy, and dictatorial."

Others shared this view on corruption. A cobalt pricing expert (R11) suggested that "…it's all economics, but not above-board economics. A lot of the underlying part of the business is large partnerships that yield personal gains". A cobalt trader (R14) agreed, saying that "…none of this money is being put into a sustainable, long-term government-led mining industry it's going into the coffers". Several interview respondents, including a German automotive executive (R18), highlighted the role of former-President Kabila and his associates:

"Cobalt is like a heritage business of the Kabila family. Everybody close to Kabila is having a good private business selling cobalt mines for a tenth or less of what they are worth and earning a margin through corruption. The real people receive almost nothing. It's making the Kabila government rich, not the people".

This view of Kabila was shared by an experienced cobalt trader (R10) who argued that:

"The history is that Mobuto robbed the mining revenues from Congo [of cobalt and copper revenues]. The present is that Kabila and his buddy Gertler and others are the beneficiaries of the current cobalt run".

8.2.5 Summary

The preceding subchapter was concerned with RQ4 which asked: how have states responded to supply risk and economic importance? In particular it sought to explore the hypothesis set out in Part I (chapter 3.5) that resource-holding states will have undertaken resource nationalist approaches in order to capture value from the cobalt sector. It did so through a focus on the DRC, by far the most important resource-holding state in the cobalt supply chain. RQ4 was set, and this subchapter was intended, to help the broader research aim of understanding how states have responded to cobalt's criticality, and how these responses have resulted in spatial and structural outcomes.

Central to this dissertation is the question of whether criticality a causal dynamic. Has it shaped the structure and geographies of supply chains? With regard to the subject-matter of this sub-chapter, were these resource nationalist actions caused by cobalt's criticality and did they lead to structural or geographic changes? Based on the findings of this chapter, the answer is 'yes'. Cobalt's economic importance prompted the government to undertake these actions in order to assert more control over, and capture more value from, its cobalt assets.

Research findings showed evident resource nationalism in the DRC cobalt sector. As set out above, the term 'resource nationalism' can encompass nationalisation and expropriation of foreign companies, export restrictions, cartel pricing behaviour or high taxation (HMHSP, 2014). The DRC can be said to have been engaged in all such behaviours. The FQM affair represents a clear case of expropriation, while the threat of an export ban has remained a feature of the cobalt market for several years. Perhaps most critically, changes to the mining code were enacted, ultimately geared towards increasing state control, boosting state power and maximising state revenues. Overwhelmingly, interview respondents gave the impression that the DRC has responded to cobalt's criticality in such a way as to maximise revenues, boost state coffers, and in many cases, boost personal wealth through corrupt means.

While this subchapter was mainly focussed on resource nationalism, it is useful to briefly reflect on the research findings with regard to other bodies of literature described in the literature review. The first is the resource curse literature which posits that resource-rich economies with capturable resource rents can fall subject to rent-seeking behaviour as revenues and royalties from mineral resources are readily appropriable and this can in turn impact economic productivity (Murshed, 2018). This has certainly been the case in the DRC and its cobalt mineral resources but does cobalt's criticality, or the cobalt-sector case study, offer anything new to the resource curse debate? The second is the GPN literature, which uses the concept of strategic coupling to explain the process of how a regional economy, or regional actors, integrate themselves into GPNs in a mutually beneficial way. Has this been the case in the DRC? Certainly, there has been coupling between DRC regional economies and lead firms and their wider GPNs but is this more akin to the 'dark side' of strategic coupling described in the literature and characterised by power asymmetries between partners (see Coe and Hess, 2011; Dawley, 2011; MacKinnon, 2012)? These questions will be revisited and discussed further in the dissertation's conclusion.

Part IV

Part II of this dissertation was concerned with observed outcomes in the cobalt sector. Part III focused on exploring the causal mechanisms that have shaped these outcomes. Part IV contains only one chapter, which contains the dissertation's conclusions.

Chapter 9 starts by revisiting key motivations for the research before outlining the novel contributions that it has made. It then revisits the research questions and the main findings presented in Part II and Part III. It also discusses methodological and data issues, limitations, and possible improvements, before discussing the implications of the research findings for policymakers concerned with critical materials. The chapter finishes by exploring areas for future research.

Part IV is highlighted in red in the schematic below.

Figure 50: Dissertation structure

Part	Part I - Research background				Part II - Outcomes in the cobalt sector		Part III - Responses in the cobalt sector		Part IV - Discussions and conclusions
Summary	Part I introduces the reader to the debates surrounding resource scarcity and critical materials and the cobalt sector. It then reviews the literature relevant to the research				Part II examines outcomes in the cobalt sector. It explores how the sector is structured and organised and how it has evolved over time		Part III is concerned with identifying some of the causal mechanisms that have shaped the observed outcomes detailed in Part II. It explores how cobalt's criticality has shaped the behaviours of firms and states		Part IV contains the research's conclusions
Chapter	C1. Introduction	C2. Resource scarcity, critical materials and the case of cobalt	C3. Theoretical debates on the nature and organisation of global supply chains	C4. Methodology	C5. A GPN approach to examining how the cobalt supply chain is structured and organised	C6. An ITN approach to charting the reconfiguration of the cobalt supply chain	C7. Firm responses to cobalt's criticality	C8. State responses to cobalt's criticality	C9. Conclusions and discussion
Summary	Introduces the research and outlines its background aims, key questions and structure	Introduces key literature on resource scarcity and critical materials before selecting a case study raw material (cobalt)	Introduces theories of international trade, theories of the firm and theories of global chains and networks relevant to the research	Discusses the use of GPN and ITN approaches for Part II and the use of case studies, a survey and semi-structured interviews for Part III	Uses a Global Production Network approach to show how the cobalt supply chain is structured and coordinated	Uses an International Trade Network approach to show how the geographies of the cobalt chain have evolved over time	Focussing on the upstream part of the sector in the DRC, the chapter looks at how firms have responded to cobalt's criticality exploring FDI and integration in particular	Focussing on the cobalt sector's major resource-holding state (the DRC) and resource-seeking state (China) this chapter explores how states have responded to cobalt's criticality	This chapter outlines key research conclusions, discusses the implications of the research findings, and outlines areas for additional study
Research questions addressed					RQ1: How is the cobalt supply chain structured and coordinated?	RQ2: How has the spatial structure of the cobalt sector changed over time?	RQ3: How have firms responded to supply risk and economic importance?	RQ4: How have states responded to supply risk and economic importance?	

Note: Red lines denote the current part

9. Conclusions and discussion

This research explored why contemporary raw material supply chains are structured as they are through a focus on the critical raw material cobalt. It has shown how the cobalt supply chain is structured and organised, how that has changed, and explored the reasons for this.

The research sought to rectify a perceived impasse in the literature on critical materials, a contemporary descendant of a wider body of literature on resource scarcity. While a glut of critical materials studies has been published over the past decade, most were focussed on the definition and classification of critical materials, rather than on exploring the complexities of their supply chains and the behaviours that have shaped their organisational structures and geographical reach. Policymakers, especially European policymakers, appeared not to have been able to advance the important critical materials agenda past the definitional phase. Since 2011, the European Commission has published three lists of critical raw materials. While this may have promoted potential raw material supply risks, other aims of the EC's critical materials agenda, such as strengthening European industrial policy, stimulating the production of raw materials in Europe, fostering more recycling of critical materials, and improving sustainable development, seem not to have been met (EC, 2018).

The research, thus, was designed to further understanding of the complex supply chains of critical materials. As set out in the introduction, this is because understanding what shapes the structure of these supply chains is important. Access to critical materials, the key inputs for a range of technologies, is essential for global prosperity, and capturing value from natural resource endowments is highly important to economic development in some of the world's poorest regions. The author felt it important to advance the debate on critical materials beyond classification and definition, and to make policymakers and industry participants aware of the complex networks that underpin critical material production and consumption, and how these networks are formed and coordinated.

9.1 Revisiting the research questions and main findings

Before discussing the key findings and wider implications of the research, it is first useful to present a short summary of the research questions posed and the key findings. RQ1 asked how the cobalt supply chain is structured and coordinated. This was explored in chapter 5 which exposed the cobalt supply chain as highly complex and global in reach.

In chapter 5, a basic linear conceptualisation of the cobalt supply chain was first put forward which enabled a discussion of the various stages of cobalt production, the key actors involved and the geographies of the supply chain. Thereafter, the chapter set out a global production network (GPN) for cobalt following the approach of Bridge (2008) who first extended GPN thinking to the extractive sector, using the oil industry as an illustrative case. This enabled an examination of the various roles played by states, institutions and firms in the cobalt GPN. The central role of lead firms was discussed before the chapter borrowed some tools from the GPN analytical toolkit to explore the configuration and coordination of networks by the firm and extra-firm actors that had hitherto been outlined. These were value, power, embeddedness, materiality and strategic coupling.

With regard to value, it was argued that resource rent and value capture are key features and coordinating factors of the cobalt GPN. Power was also argued to be a coordinating factor, mainly through an actor's control of cobalt assets or cobalt units, which is something that changes of time. Corporate power, collective power, institutional power, state power and supply chain power were all outlined as key dynamics affecting the structure and organisation of the cobalt supply chain. With regard to embeddedness, it was argued that territoriality matters in the cobalt GPN. In particular, it was argued that the geological concentration of cobalt in the DRC and high concentration of cobalt refining in China had a huge bearing on the structure of the cobalt supply chain. Value creation, enhancement, and retention in the wider production network is influenced by the cobalt GPNs territorial embeddedness in these states and the cobalt GPN's organisational and network structures are shaped by such a significant grounding in these jurisdictions. With regard to materiality, it was shown that the cobalt network is organised around moments of material transformation and material forms and qualities shape the configuration of the network. And finally, it was shown that processes of strategic coupling, uncoupling, and recoupling have had an important bearing on the organisation and structure the cobalt GPN.

Returning to the research question, how then is the cobalt supply chain structured and organised? The findings of this research are that the cobalt supply chain fits neatly with the GPN framework. Far from a linear supply chain structured around moments of material transformation, the cobalt supply chain is the result of a multitude of linear/vertical as well as non-linear/horizontal relationships between firms, states and institutions. Its structure is constantly evolving, the result of shifting actor-specific firm and non-firm strategies. Responses to global capitalist dynamics underpin the strategies of actors involved in the sector. Through responding to various dynamic pressures and incentives these actors, such as lead firms like Glencore, conjure global networks to create, enhance and capture value. Thus, the basic hypothesis that the cobalt supply chain is a network of connected economic and non-economic actors, coordinated by a global lead firm, and producing goods or services across multiple geographical locations for worldwide markets, was confirmed.

In answering RQ1, the research tested the viability of using a GPN approach to better understand a critical material supply chain. While the GPN literature is mostly focussed on manufacturing and service sector examples, it is clear that the logic of GPN thinking is easily applicable to more niche networks and chains. Enabling an understanding of the coordinating, organisational and controlling forces at play in a global supply chain, as well as the importance of inter-firm relations as well as firm–state relations, is highly useful in a critical material sector setting. As outlined in the introduction, what is missing from the current policy debate over extractive industries, and the literature on critical materials, is a sense of the relational way in which production is organised via inter-firm and extra-firm networks that massively exceed the boundaries of the nation-state (Bridge, 2008; p.393). This analysis has served to move analysis of the cobalt sector beyond the realms of linear conceptualisation and mere definition and placed it within a framework where the causal mechanisms underpinning and shaping sectoral patterns can be explored. Later chapters of this dissertation prompted some additional reflections on the GPN framework. These are discussed further below.

RQ2 asked how the spatial structure of the cobalt sector has changed over time. This was explored in chapter 6 which examined the International Trade Network (ITN) for cobalt units, to show the evolution of import-export relationships between all countries engaged in cobalt trade between 2007 and 2017. Trade data analysis represented the best way to examine changes over time to the interdependencies that exist between countries engaged in the cobalt supply chain. This, in turn, formed a basis to better understand if and how cobalt's criticality has brought about a reconfiguration of the cobalt sector's geographies.

Four ITNs for cobalt were analysed, based on groupings of different harmonised system codes that represented the trade of cobalt in its different forms. These were: the cobalt ores and concentrates ITN, the cobalt intermediates ITN, the refined cobalt chemicals ITN, and the refined cobalt metal ITN. The analysis was able to show how the trade networks for these different cobalt products (produced at different stages of the linear supply chain) have evolved and thus uncover more stylised facts about cobalt trade than would have been the case if cobalt trade were simply investigated at an aggregate level.

The results showed the increasing importance of certain exporting and importing nodes within each of the four ITNs examined. With regard to the cobalt ores and concentrates ITN, the analysis illuminated the emergence of China and the DRC as the world's dominant importing and exporting nodes respectively. Trade between these two nodes increased over time and by 2017, Sino-Congolese trade represented 95% of all trade in the cobalt ores and concentrates ITN. Similarly, analysis of the cobalt intermediates ITN also served to highlight the growing importance of bilateral trade relations between the DRC and China. Trade between these two nodes increased over time and by 2017, Sino-Congolese trade represented 100% of all trade in the ITN. These findings fit neatly with the findings of chapter 5 which showed the emerging dominance of the DRC as the world's major mine producer, and China as the world's leading refined producer.

Analysis of the downstream part of the cobalt chain, the refined cobalt chemicals ITN and the refined cobalt metals ITN, confirmed that despite the dominance of the DRC upstream, there are numerous other important nodes elsewhere in the network. Analysis of the refined cobalt chemicals ITN showed how most exports in the ITN were from three exporting nodes: China, Belgium and Finland. Analysis of the refined cobalt metal ITN, however, foregrounded the importance of Canada and Finland as exporting nodes and Japan, the USA and China as importing nodes.

Given cobalt's territorial embeddedness in certain states, it was hypothesised that the geographies of the sector would not have changed radically as only certain states can serve as exporters. This proved to be the case with the DRC's role in the network highlighting the importance of geology to the geographies of any extractive sector. When all four cobalt ITNs are considered, the cobalt network appears to fit well with the traditional core-periphery model. Raw materials are produced and exported from nodes in the periphery, most notably the DRC, to nodes in the core (such as China, South Korea, and the USA) and consumed in the manufacture of higher-value cobalt-bearing products.

It was also expected that countries without cobalt resources would have sought to ensure access to cobalt units by diversifying their supply chains and increasing their imports. China's growing importance as an importing node serves to partially support this hypothesis. China, a country without significant cobalt resources but the world's leading refined producer and consumer, increased its imports of unrefined cobalt significantly over the period under analysis. However, far from having diversified its supply base, Chinese imports have been increasingly sourced from the DRC suggesting little supply chain diversification. Ultimately, this was underpinned by firm- and state-level dynamics (as shown in Part III). Most critically, supported by state policies, Chinese FDI in DRC cobalt-sector assets increased sharply over the period under analysis. Thus, an increasing amount of cobalt trade between the two countries has become intra-firm trade. Research findings, therefore, show how Chinese firms have opted to ensure access to cobalt units through the acquisition of productive assets in Central Africa, rather than by diversifying their supply chains and seeking to acquire cobalt units from a greater range of source countries.

Returning to the research question, how has the spatial structure of the cobalt sector changed over time? The research findings show that there have been few changes in the geographical scope of the supply chain. The number of nodes engaged in cobalt trade remained constant over the period under analysis. Further, the same states active in the cobalt supply chain in 2007 remained active in 2017, and thus the geographies of the cobalt sector remained broadly similar. Nonetheless, the importance of certain geographies to the cobalt network, namely the DRC and China, has intensified. While the upstream part of the supply chain remains physically grounded in the DRC, there has been a reconfiguration of the downstream cobalt chain towards China. As of 2017, China was the biggest importer in the cobalt ores and concentrates and cobalt intermediates ITNs, a top-three importer in the cobalt metal ITN and the biggest exporter in the cobalt chemicals ITN.

RQ3 asked how firms have responded to supply risk and economic importance and this was explored in chapter 7. The chapter aimed to test two hypotheses. The first was that in response to cobalt's supply risk and economic importance, resource seeking, where firms seek to acquire resources that are not available domestically, would have taken place. It was expected that FDI would have increased in the cobalt sector as firms attempted to acquire raw materials not available domestically.

Research findings suggest that this was indeed the case. The analysis showed how DRC cobalt extraction, once exclusively in the hands of one company, is now characterised by high levels of (especially Chinese) FDI and public-private partnerships. Once exclusively a Congolese-controlled sector, it was shown that by 2017, 42% of DRC cobalt mine production in tonnage terms could be attributed to Chinese firms and a further 33% to one Swiss firm, Glencore, the single-largest producer of cobalt in the world. DRC firms, by comparison, accounted for 14% of cobalt mine production in 2017 (down from 100% in 1995).

The subsequent analysis explored the behaviours that had caused this shift. The findings of the cobalt-sector survey and semi-structured interviews suggested that supply risk and economic importance were key reasons for foreign direct investment in the cobalt sector.

With regard to supply risk, the consensus amongst respondents was that security of the supply was essential to firm survival and, therefore, that efforts to mitigate supply risk, as well as other risks related to corporate social responsibility, caused firms to undertake FDI. Interviews and survey responses confirmed that firms, especially Chinese firms, invested heavily in upstream cobalt assets in Central Africa in order to secure access to cobalt units and increasingly, to guarantee the provenance of the cobalt they consumed. The research showed how Chinese refineries are the biggest consumers of cobalt yet have limited domestic material to process. Having originally bought material on the open market, increasingly Chinese firms have sought to invest in upstream assets (in the DRC) in order to guarantee supply. This has been done with the support of the state, which has encouraged the acquisition of overseas mineral assets through its Go Out (走出去)" policy, and which has strong ambitions to be a world leader in electric vehicles and related industries.

Cobalt's economic importance, too, was cited as a key reason underpinning FDI decisions. Cobalt has always been an important industrial material, used in key sectors such as mining and aerospace. The significant growth in demand for cobalt over the period under analysis was due to the fact that cobalt has, over the past two decades, become an essential ingredient in lithium-ion batteries used in portable electronics. This growth in demand, supported by the expectation that future demand for cobalt will grow enormously because of cobalt's use electric vehicle batteries, has made a wide range of actors consider FDI in cobalt assets in order to ensure access to the raw material. The analysis confirmed that the cobalt landscape has evolved substantially over the past twenty years, and the nature of investment in the DRC, its principal source, had also evolved. When foreign investment in DRC cobalt assets first began, in the early 2000s, the motivation of foreign firms was principally that of access to raw materials and profit making. Today, security of supply and sustainability of supply are primary factors. Ultimately, supply risk and economic importance are interrelated motivations for FDI. As a retired cobalt trader put it, "…the bottom line is economic but to protect the bottom line you need to protect the supply line".

Aside from cobalt's criticality, research findings show how other factors have led firms to undertake FDI. In particular, the Chinese regulatory environment and the pursuit of copper and nickel units were highlighted as key factors. The analysis also showed that FDI in the cobalt sector has principally been undertaken by Chinese refined producers of cobalt, supported by Chinese financial institutions and the Chinese regulatory environment. Despite the huge interest in cobalt procurement because of the anticipated demand from the electric vehicle sector, there has been limited FDI from end-users of cobalt such as automotive firms, especially ex-China firms.

The second hypothesis, closely related to the first, was that in responses to cobalt's criticality, more vertical integration would have occurred in the cobalt supply chain. It was expected that increased vertical integration would occur as firms try and integrate backwards, bringing supply of feedstock within the boundaries of the firm, or integrate forwards, bringing the production of higher-value cobalt products within the boundaries of the firm. The chapter explored this through a detailed case study of Huayou Cobalt, the world's biggest refined cobalt producer, which has undergone considerable forward- and backward integration since it was founded in 2002.

Responses to the cobalt-sector survey and semi-structured interviews suggested that supply risk and economic importance were key motivations for vertical integration. The consensus among interview respondents was that historically the cobalt supply wasn’t too integrated, but that it had become increasingly so. Respondents attributed the decision to integrate backwards to concerns over security of supply, with integration bringing supply of feedstock within the boundaries of the firm. The decision to integrate forwards was attributed to the desire to maximise value capture in evolving supply chains and markets, especially those related to electric vehicles. As well as supply risk and economic importance, numerous other factors including reputational risk, value capture, price volatility, and Chinese industrial policy were cited as reasons for increased integration in the cobalt supply chain.

RQ4 asked how states have responded to supply risk and economic importance. State-level responses to cobalt’s criticality were explored in chapter 8 which looked to test two hypotheses. The first was that in response to cobalt’s supply risk and economic importance, resource-holding states will have undertaken resource nationalist approaches in order to capture value from the cobalt sector. The DRC was selected as a case study example of a resource holding state, given that it has by far the world’s largest cobalt reserves and resources, and is the largest mine producer of cobalt globally (USGS, 2016c). Research findings showed how, over the period under analysis, the DRC state engaged in various activities that can be classified as resource nationalism. This includes the expropriation of a cobalt asset; the repeated threat of a ban on the export of cobalt ores and concentrates and changes to the mining code, ultimately geared towards increasing state control, boosting state power and maximising state revenues. The consensus amongst respondents was that the DRC has responded to cobalt’s criticality in such a way as to maximise revenues, boost state coffers, and in many cases, boost personal wealth through corrupt means.

The second hypothesis was that in response to cobalt’s supply risk and economic importance, resource-seeking states would have created the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value from the cobalt sector. China was selected as the case study resource-seeking state as it is by far the world’s biggest importer of unrefined cobalt and producer of refined cobalt. Research findings showed how cobalt’s criticality led to a concerted effort on the part of China to gain control of the DRC cobalt sector. Cobalt’s economic importance, especially to the EV sector but also to electronics and other sectors, makes access to it of vital importance to the Chinese economy. And its supply risk, a result in particular of the high concentration of production in the DRC, means that Chinese actors have worked hard to ensure access to cobalt units through investment. Analysis showed how acquisition of DRC cobalt assets was made possible by a combination of China’s “Go Out (走出去)” policy, the regulatory framework in China designed to facilitate and support FDI in order to nurture globally competitive Chinese firms and China's "12th Five-Year Plan on National Economic and Social Development" which promotes electric vehicles as a national strategic industry supported by various subsidy and incentive schemes.

Research findings, therefore, showed that states have responded to cobalt's criticality, albeit in different ways. These differences are in part to do with a state's position in the cobalt supply chain. It stands to reason that the behaviours of a resource-holding state would differ from those of a resource-seeking state. Nonetheless, state responses in the two case study examples are moreover grounded in wider macroeconomic, political and cultural realities. China's responses to cobalt's criticality can be characterised as various parts of a strategic plan to drive economic, industrial and technological development. Its FDI in cobalt assets, and the fact that its companies have integrated forwards and backwards in the cobalt supply chain, are the result of regulations and development plans designed to bolster existing firms' competitive positions and well as to create and develop new growth sectors for the economy. Conversely, far from representing parts of a strategic plan, the DRC's responses to cobalt's criticality appear grounded in little more than corruption and opportunism.

9.2 Critical reflections on the theoretical approaches considered and areas for future research

This chapter presents an opportunity to critically assess and reflect on the theories and approaches used in this dissertation. Let us start with reflections on the GPN approach. This has proven to be a useful tool for conceptualising the cobalt supply chain. Unlike its chain-based antecedents, the framework is able to accommodate many of the complexities of a contemporary global supply chain. It incorporates the interactions of a wide variety of actors, both firm and non-firm. It takes into account various spatial scales and territories. It denotes useful variables (value, power and embeddedness) to help explore the configuration and coordination of supply chains. And it offers some causal explanation for regional development outcomes. Thus, it has been a considerably useful framework for exploring and explaining the sprawling, global cobalt supply chain and its diverse actors and geographies.

The research findings lead to two main comments and observations about global production networks, which might make for interesting areas for future study and development of the GPN approach. The first relates to lead firms. Lead firms are of fundamental importance to GPNs. They coordinate the value-added activities of various other economic actors and conjure production networks to create, enhance and capture value. They are self-interested actors with the '…capacity to coordinate and control directly its production network – be it in the role of buyer, producer, coordinator, controller, or market-maker, or a composite of one or more of these roles' (Coe and Yeung 2015, p. 40). They configure GPNs to their advantage and engage in bargaining and cooperation with regional institutions and actors.

As noted in the concluding remarks to chapter 7, the lead firms we have encountered in this dissertation are not the typical lead firms from the GPN literature. To a certain extent, this is a reflection of the fact that most of the GPN literature focusses on the manufacturing and service sectors and that few of the contributions that focussed on extractive industries examined lead firms in considerable detail (Bridge, 2008; Bridge and Bradshaw, 2016; Dicken, 2015; Gibson and Warren, 2016; MacKinnon, 2013; Steen, and Underthun, 2011). But while extractive sector firms are very different from those in secondary and tertiary sectors, this dissertation has shown that even within the relatively small world of cobalt, there is considerable heterogeneity in lead firm type.

This dissertation has introduced several cobalt lead firms, and it is useful to revisit three in brief here. The first is Huayou Cobalt, which while publicly traded since 2015, has strong ties to the Chinese government, both through its shareholding and its financing. It has assets in China, the DRC and Indonesia, and spans the cobalt supply chain from mine production to battery recycling. The company operates within a unique regulatory and policy environment, which includes the "Go Out (走出去)" policy supporting FDI in mineral assets and promotes the creation of globally competitive Chinese firms with a portfolio of locational assets.

The second is Glencore, a multinational commodity trading and mining company, headquartered in Switzerland. Since its creation in 1994 it has grown into one of the world's leading producers and traders of commodities and Switzerland's largest company. It traded as a private company until it was listed on the London and Hong Kong stock exchanges in 2011. It has cobalt operations in Australia, Canada, the DRC, Norway and Zambia, is the largest cobalt mine and intermediate producer in the world and although it also produces refined cobalt it, unlike Huayou, has not moved further downstream into battery production or recycling.

The third is Gécamines. As set out in chapter 7.1.1, the DRC's state-owned mining enterprise holds unique and significant power and control over the country's cobalt assets. It holds minority shareholdings in most operational cobalt mines and is the holder of the richest and largest selection of mining permits in the country. But while formerly the world's largest producer of refined cobalt, years of mismanagement set against the backdrop of civil war have seen its assets fall into disrepair and its production volumes diminish.

These three examples highlight the diversity of the types of lead firm operating in the cobalt supply chain. It stands to reason that different types of lead firm respond to capitalist dynamics such as costs, markets, risk, and criticality differently. Their differences result in different strategies and thus different outcomes. And their differences mean differing approaches for bargaining and cooperation (or coupling) with regional actors, which means different development outcomes. This raises interesting questions for future GPN research regarding how different types of firm respond to global dynamics, generate value capture trajectories and bring about regional development outcomes.

The second observation about global production networks relates to strategic coupling. As is the case with lead firms, concepts of strategic coupling have been informed mainly by the experiences of manufacturing and service sectors. This dissertation follows MacKinnon (2013) by considering strategic coupling in a resource dependent economy. While an assessment of regional development outcomes in the DRC was not a core motivation of this research, some comments can nevertheless be made here.

In his examination of iron ore production in Pilbara, Australia, MacKinnon (2013) argued that the relationship between GPNs and regional assets was more akin to structural coupling in terms of its partial and asymmetrical nature, with crucial inputs such as labour and materials being supplied largely from outside the region.[25] The same can be said of the relationship between cobalt lead firms touching down in the DRC and regional players. As one interview respondent noted, many Chinese firms "…import most of the materials to use in Kolwezi from China, including materials for industry and for the workforce" (R27). The same is true of workers themselves. A visit to Lubumbashi and Kolwezi leaves the visitor in no doubt as to the vast number of Chinese workers living in the region: Chinese road signs, shops and even casinos are ubiquitous. Thus, in the DRC example, too, the process of coupling appears asymmetrical and more structural than strategic.

In the GPN literature, strategic coupling is the process of how a regional economy, or regional actors, integrate themselves into GPNs in a mutually beneficial way. Owing in part to the structural nature of the coupling process, many local workers and communities in the DRC are not realising the economic benefits of the coupling process. But furthermore, the DRC's reputation for corruption, and for human rights abuses in its cobalt sector (see chapter 3.2.3.1), begs the question of whether the country has in fact witnessed developmental curses as a result of strategic coupling. Are there benefits to strategic coupling in a country where, according to UNICEF, approximately 40,000 children work in mines, many of them mining cobalt (Amnesty International, 2016)? It is institutional conditions that shape

[25] The debate of the various forms of coupling is described in chapter 3.4.3.1 and is not repeated here.

development practices and processes and it seems reasonable to argue that the DRC lacks the conditions required to facilitate mutually beneficial strategic coupling that results in positive developmental outcomes. Instead, corruption and weak governance endure, and thus while lead firms can reap the benefits of coupling, the benefits to local communities are squandered. In some cases, value capture trajectories have led not to positive developmental outcomes, but instead to personal enrichment. Coupling has occurred not with regional actors, but with corrupt officials. The term “corrupt coupling” may be more appropriate in this context.

These conclusions resonate with the various references in GPN literature to the ‘dark side’ of strategic coupling, shorthand for the negative consequences of power asymmetries between states and firms and typified by corporate capture of regional institutions (Coe and Hess, 2011; Dawley, 2011; MacKinnon, 2012; Rutherford et al. 2018). These contributions have, to varying degrees, explored incidences of coupling where was power disproportionately concentrated in the hands of the firm, resulting in negative outcomes. This research highlights a situation where power is disproportionately shared between the hands of the firm and corrupt elements of the state at the expense of local actors. The cobalt case study, like MacKinnon’s iron ore example, demonstrates the relevance of some long-standing themes of geographical political economy such as external domination, uneven development, conflicts over value and the distinction between development ‘of’ a region and development ‘in’ a region (MacKinnon, 2013). Both raise some interesting areas for future research, especially with regard to the role of the state and good governance in ensuring positive developmental outcomes from lead firm value capture trajectories.

Research findings also prompt discussion of some of the theories of the firm. This dissertation has paid considerable attention to multi-national firms, especially Chinese firms, which have invested in DRC cobalt assets. The research has illuminated certain key conditions that have underpinned and supported their FDI and vertical integration.

The first is support from their home state. Acquisition of DRC cobalt assets by Chinese firms has been made possible and indirectly encouraged by various policies and strategies. The “Go Out (走出去)” policy encourages Chinese enterprises to invest overseas, especially in mining and energy assets. The regulatory framework in China seeks to facilitate and support FDI in order to nurture globally competitive Chinese firms by ensuring that these firms have a portfolio of locational assets which provide better access to markets. And China’s “12th Five-Year Plan on National Economic and Social Development” outlines EVs (which require a large supply of cobalt) as a national strategic industry supported by various subsidy and incentive schemes. These factors, in combination with access to (often state) finance and the risk appetite to invest in the DRC, have underpinned China's acquisition of African cobalt. These can be seen as enabling factors for integration and FDI.

The second is the investment climate of the overseas state. The DRC's cobalt sector is palatable only to a certain type of investor. The association with corruption and human rights issues deter many from a corporate social responsibility perspective, while concerns over resource nationalism and dealings with gatekeeper Gécamines dissuade others. As an interview respondent from a major Japanese trading company (R34) noted "…for us [Japanese firms] the Congo is not really an option. Japanese companies will not tolerate the risks". Nevertheless, investment has continued and over the period under analysis and the risks of investing in the DRC have not deterred the likes of Glencore, Huayou Cobalt or their Chinese competitors. As this dissertation has showed, while the DRC is a unique and challenging operational environment, the potential economic and strategic benefits of producing cobalt in the DRC are considerable. The types of advantages of operating in the DRC are slightly at odds with the traditional benefits that one might expect from the GPN strategic coupling literature (access to skills, labour etc). Indeed, they are also distinct from the typical economic, institutional and social locational advantages that Dunning (1988) outlines, gained from activity in a specific location which can boost profitability, such as lower costs or taxes. So too are the more underhand advantages that some firms have benefited in cases that have seen "...tens-of-millions of dollars… exchanging hands in return for mining licenses that were going sideways either to Switzerland or into private election funding" (R9).

State-level dynamics and policies are central factors which have enabled FDI and vertical integration in a cobalt-sector context. As Bucheli (2007), notes with regard to vertical integration, this research argues that FDI should be viewed as not only an economic process but a political process, influenced by the relationships between the firm and the host country, the firm and its home country and the two countries in question.

Finally, it is also useful to reflect on the theories of the state with natural resource endowments introduced in the literature review. Has this study of cobalt's criticality offered anything new to the debates on resource nationalism or the resource curse? The dissertation makes the case that cobalt's criticality has given rise to resource nationalism, at least in a DRC-cobalt context. The FQM affair (see chapter 8.2.2) serves as a clear example of asset expropriation, a form of resource nationalism. The case fits neatly with the 'obsolescing bargaining model' attributed to (Vernon, 1971; Mikesell, 1971) which sees power dynamics between governments and multinational corporations shift over time in the government's favour. Once the Frontier mine asset was developed, power shifted in the government's favour with FQM having sunk considerable finance into asset development. Using the shorthand of GPN literature, this could also be termed a form of 'uncoupling' initiated by the state. Power and agency can be said to have altered over time in the case of Frontier, changing the bargaining powers and positions of the actors involved.

With regard to the resource curse, as set out in the literature review, Vahabi (2017) makes the useful distinction between economic resource curse literature and political resource curse literature. The former refers to the notion that resource rich economies tend to grow more slowly than resource-poor economies and is commonly associated with the macroeconomic problems faced by states which received a windfall from natural resource booms in the second half of the twentieth century (Murshed, 2018). The DRC does not appear to fit the economic resource curse mould. While cobalt booms may lead to higher revenue in the DRC, corruption is likely to hinder the extent to which this will translate into spending and thus an economic reallocation in which the country moves towards a service-based economy is unlikely. Here, the curse of corruption protects the DRC from the economic resource curse.

It is useful, however, to question whether the resource curse could apply to critical materials. As Overland (2019: 37) notes, "…some actors now argue that the transition to renewable energy will lead to the reappearance of the resource curse among countries rich in critical materials and/or with large, exportable surpluses of renewable energy". This raises the question of whether like some oil producers in the past, their apparent wealth will lead to a weakening rather than a strengthening of their position in the world (Overland, 2019: 37). From an economic perspective, it is unlikely that critical materials will generate the revenues enjoyed by oil-producing states. Thus, a weakening of global positioning in purely economic terms seems unlikely. However, the critical materials spotlight is likely to mean that the DRC and other developing countries remain the focus of resource curse analyses. Certainly, the DRC shows all the hallmarks of the political resource curse, characterised by authoritarian, corrupt resource-rich states prone to civil wars (Ross, 1999; Collier and Hoeffler, 1998). Cobalt's economic importance and the supply risks associated with its production in the DRC will mean the country continues to be associated with the political resource curse for the foreseeable future. This is for good reason as evidenced by the research findings of study which highlight that rent-seeking behaviour, a key feature of the resource curse, has been pervasive in the DRC.

9.3 Discussion of novel contributions: does criticality shape the structure of supply chains?

This research has made several original contributions. Its principal conceptual contribution is showing how the factors that make materials critical (supply risk and economic importance) influence the behaviours of firms and states and thus bring about reconfigurations of supply chains and shape the geographies of resource extraction, production, and consumption.

The research has shown that cobalt's criticality affected firm behaviour, prompting some firms to engage in foreign direct investment and vertical integration. Nevertheless, responses to cobalt's criticality have varied as several factors bear on responses to criticality. The heterogeneity of lead firm types and the different policy and regulatory frameworks they operate in impact responses to criticality and thus affect outcomes.

The research has also shown that cobalt's criticality affects state behaviours in different ways. It prompted the DRC state to enact resource nationalist policies, while at the same time led China to create the conditions necessary for firms to acquire overseas cobalt assets and develop domestic capabilities in order to capture value. While, the author notes that other factors alongside criticality contributed to these outcomes, the research concludes that criticality has shaped the structure and geographies of the cobalt supply chain.

The research has also made some empirical contributions. First, the research contains the first known application of the Global Production Network (GPN) approach to a critical material market. The cobalt supply chain has, therefore, been presented in a new way. Rather than being set out as a linear production chain, this research has foregrounded the diverse roles of institutions, states and firms in the cobalt network. Thus, as opposed to a supply chain structured around moments of material transformation, the cobalt supply chain has been shown to be formed of a multitude of linear/vertical as well as non-linear/horizontal relationships between firms, states and institutions, influenced by factors such as value, power, embeddedness and materiality.

Second, the research also contains the first known application of an International Trade Network (ITN) approach to one commodity. All ITN analyses to date have been at the aggregate or commodity group level, while instead, this research applied the ITN approach to different forms of cobalt to uncover stylised facts about the trade of each. This novel approach outlined the temporal and geographical evolution of several sub-parts of the cobalt supply chain. It clearly highlighted the growing importance of certain nodes (states) over time and how the international trade of different types of cobalt (ores, intermediates, metal, and chemicals), has evolved differently.

These novel approaches have unearthed original insights and observations about the relatively secretive cobalt supply chain. It is hoped that they have helped further understanding, in a cobalt-sector context at least, of the relational way in which production in critical raw material supply chains is organised via inter-firm and extra-firm networks (Bridge, 2008; Coe et al., 2008; Coe and Yeung, 2015).

Part I of this dissertation expressed a hope that this research could address some gaps, and areas for further examination, set out in recent literature. It was hoped that:

1. The research would contribute evidence towards the development of a more dynamic theory of global production networks that can better explain the emergence of different firm-specific activities, strategic network effects, and territorial outcomes (Yeung and Coe, 2015);

2. Research findings would help to answer recent calls to explore how resource scarcity within GPNs evolves temporally and how firms operating in GPNs are able to adapt to resource scarcity (Gibson and Warren, 2016);

3. Research findings would help to identify the role of states and other non-firm actors in contemporary production networks (Bridge, 2008; Horner, 2016);

4. Research findings would confirm whether there are specific outcomes – technological, operational, and geographic – which can be expected within supply chains when limitations on materials emerge (Alonso et al., 2011).

With reference to (1), the research has shed some light, in a cobalt-sector context, on the causal links that connect through from the structural dynamics that underpin global production network formation and operation to development outcomes (Coe and Yeung, 2015). It has shown how two key dynamics (supply risk and economic importance) led firms to respond with strategies (notably foreign direct investment and vertical integration) in order to capture value. It has also shown how states undertook different strategies in response to these dynamics, depending on their position in the network. China, which required access to cobalt units, created the conditions for foreign investment to secure them and set in place various frameworks to develop globally competitive firms. The DRC, a resource-holding state with huge cobalt resources, meanwhile pursued a strategy of resource nationalism, in order to increase state income. It has argued that the heterogeneity of firm and state types impacts responses to criticality, and ultimately network and territorial outcomes.

With reference to (2), the temporal evolution of resource scarcity was explored across several chapters. Chapters 5 and especially 6 showed that the growth in cobalt demand and supply brought about not only an increase in international trade volumes but also a reconfiguration of the cobalt trade network. Increasingly, the DRC and China have become the two central nodes for mine and refined cobalt production respectively. These chapters showed how territorial forms change over time and that in the cobalt GPN there has been a clear move Eastwards, as more and more cobalt sector value capture has occurred in China and other Asian countries. Chapter 7 showed that firms operating in GPNs are able to adapt to resource scarcity through various strategies, although different actors respond differently to capitalist dynamics. This research foregrounded analysis of foreign direct investment and vertical integration, two ways how firms operating in GPNs are able to adapt to resource scarcity.

With reference to (3), the research outlined the diverse role of states in the contemporary cobalt network and confirmed that production networks are highly territorial. The GPN approach set out in Chapter 5 showed how the state grants exploration licenses and permits, receives taxes and royalties, shapes legal and environmental norms and greatly impacts production network dynamics through creating (or removing) logistical and financial barriers and constraints. Chapter 8, through its focus on China and the DRC, explored the wide range of outcomes that diverse state actions have had on the cobalt network. It showed how the Chinese state has been proactive in its attempts to enable its firms to dominate the cobalt supply chain and that the wide-scale acquisition of DRC cobalt assets was made possible and indirectly encouraged by various policies and strategies. In stark contrast, the chapter also showed how the DRC state has for years engaged in resource nationalist behaviours in order to maximise revenues, boost state coffers, and in many cases, boost personal wealth through corrupt means.

The research has also shown how states operate cobalt production facilities in a number of jurisdictions through state-owned mining enterprises or joint-venture operations with private/public companies. Chapter 7 and Chapter 8 outlined the central role played by state-owned Gécamines in the DRC in controlling access to cobalt and copper units. Further, these chapters also showed how Chinese SOEs have supported the acquisition of Congolese cobalt assets in line with the Chinese regulatory framework.

With regard to (4), chapter 2 outlined an Alonso et al., (2011) study of the cobalt supply chain, entitled *Material Availability and the Supply Chain: Risks, Effects, and Responses*. This argued that there are specific outcomes – technological, operational, and geographic – which can be expected within supply chains when limitations on materials emerge (Alonso et al., 2011). It was argued that supply chain stakeholders may redesign their products to use less cobalt or substitute materials (technological), the upstream supply chain may reconfigure to tap into new sources (geographic), and downstream firms may alter inventory practices or work to recover alternative materials streams (operational).

This research has unearthed some technological, operational, and geographic outcomes from the recent period of perceived cobalt criticality. In terms of geographic outcomes, like the Alonso et al. (2011) study, this research has shown that the supply chain has been reconfigured to tap into new sources as described by the detailed analysis of FDI and integration set out in Part III. In terms of technological outcomes, in chapter 7.2.2, respondents noted how in part because of its high price and link to the DRC, cobalt was being substituted out of batteries. And in terms of operational outcomes, the Chinese investment in cobalt recycling described by respondents in 8.1.5 suggests new approaches to metal recovery are being explored.

9.4 Areas for future research on critical materials

How does cobalt appear to compare with other critical materials sectors? Each of these is characterised by being of considerable economic importance but with a high concentration of mine production in one country. But is cobalt a typical example, or a special case? Let us return to the other critical material shortlisted for closer examination in chapter 2.4: niobium.

Niobium is nearly all produced by three firms: two in Brazil, which counts for the vast majority of global production, and one in Canada. The industry is effectively an oligopoly.

Companhia Brasileira de Metalurgia e Mineração (CBMM), by far the world's largest producer of niobium, is 70% owned by Brazil's Moreira Salles family (Roskill, 2017b). The family sold the remaining 15% stakes to a Japanese/Korean consortium and a Chinese consortium in 2011. These consortia were comprised of many of CBMM's major customers, thus securing a long-term relationship.

China Molybdenum (CMOC) was established in 2006 and listed on the Hong Kong stock exchange the following year. CMOC undertakes mining and processing of molybdenum, tungsten, copper, gold and other precious and base metals. The company's two largest shareholders together own 62%. Luoyang Mining Group (32%) is controlled by local authorities in the city of Luoyang, central China, and Cathay Fortune (30%) is a Chinese private equity group (Roskill, 2017b). CMOC bought Anglo American's niobium and phosphates businesses in Brazil for US$1.7Bn in 2016 (Roskill, 2017b).

Magris Resources, based in Canada, owns the Saint-Honoré mine and ferroniobium converter in Québec, which was owned by TSX-listed gold producer IAMGOLD until 2015. Magris's financial backers are Singapore sovereign wealth fund Temasek Holdings, CEF Holdings, a Hong Kong investment firm, and Canadian Imperial Bank of Commerce (Roskill, 2017b).

Here we see some similarities with cobalt. All three producing firms have very different ownership structures with a combination of state-, private and public owners. As is the case with cobalt, recent FDI has placed a considerable share of all three entities in Chinese hands. It is highly likely that this too has been underpinned by China's regulatory framework, designed to nurture globally competitive

Chinese firms and encourage overseas investment in mineral assets. CBMM's partial sale to its customers also serves as an example of vertical integration. Are these similarities a coincidence, or do they represent similar firm reactions to criticality?

Unquestionably there are considerable differences too. The research has shown how the cobalt supply chain has been heavily shaped by its connections to the DRC, its major resource holding state. While resource nationalist rhetoric related to niobium production was evident during the campaign trail for Brazil's recent presidential elections (Spring, 2018), there have been no incidents of rent-seeking or corruption. Thus, it is likely that the process of strategic coupling, and as a result, regional development outcomes have been very different.

This research explored why contemporary critical material supply chains are structured as they are through a focus on cobalt. While it was beyond the scope of this research to investigate other critical material supply chains to a similar degree of detail, doing so represents a fertile area for future research. This is for several reasons.

First, detailed examinations of critical raw material supply chains will be invaluable evidence bases for an important policy agenda. Not much is known about the complex supply chains of critical materials, yet they underpin a range of critical technological, military and industrial applications. It is important for future sustainability agendas and policy programmes to be developed on the basis of a full understanding of how critical materials supply chains are structured and coordinated, and the reasons for this.

Second, the setting out of a global production network for cobalt represented the first-known application of GPN thinking to a critical material supply chain. Applying this framework to other critical materials would enable comparison of their GPNs, which could help foster a better understanding of how supply chains are structured and coordinated and whether, besides their 'critical' label, they share any other commonalities. The application of a GPN approach to other critical materials would help further recent calls to explore how resource scarcity within GPNs evolves temporally; how firms operating in GPNs are able to adapt to resource scarcity (Gibson and Warren, 2016); and the role of states and other non-firm actors in contemporary production networks (Bridge, 2008; Horner, 2016). Further, more empirical critical material GPN studies would help provide evidence towards explaining patterns of uneven economic development in the global economy through comparing types and incidences of strategic coupling.

Third, the application of an International Trade Network (ITN) for cobalt units also represented a novel approach. As noted in the literature review, while previous studies have taken a commodity-specific approach to analysis, these studies employed data on specific commodity classes to identify stylised facts about the ITN. There have, to date, been few studies of commodity specific ITNs and hardly any focussed on only one metal or mineral. Thus, setting out an ITN for other critical materials represents another interesting avenue for future research. Doing so would enable a comparison of critical material ITNs, which could help to further understanding of whether or not trade architectures are heterogeneous across commodity-specific networks. Future analysis could also look to examine the extent to which the topological properties of aggregate ITNs are dependent on those of the commodity specific networks that underpin them. Analysis of the ITNs of critical materials and other commodities would likely be of considerable interest at present, given the prevailing trade wars between the USA and China. In-depth analysis of this kind could be used to better understand the impacts of tariffs only global trade networks.

Finally, this research has drawn conclusions regarding how criticality affects firm and state behaviours. While this holds true in a cobalt-sector context, it would be useful to explore whether they are generalisable to other critical materials supply chains. For example, has criticality led to firms undertaken foreign direct investment and integration in the antimony supply chain? Or have resource-holding states undertaken resource nationalist policies in Rare Earths supply chain? Asking these questions, and applying the framework set out in this dissertation, is a crucial next step to exploring its conceptual contribution to the field.

9.5 Limitations and methodological and data improvements

This research employed a mixed-method design. Desk-based research and quantitative analysis were combined with qualitative research. For the most part, qualitative research built directly on the results of desk-based and quantitative research. Broadly speaking, outcomes in the cobalt sector were examined through quantitative research (Part II), while the behaviours that underpinned these outcomes were explored through qualitative analysis (Part III).

Methodologically, Part II utilised recognised interpretive frameworks and approaches for conceptualising and documenting the complex global economy. The author is content that, in doing so, Part II represents more than a mere description of the cobalt supply chain and its geographic evolution. Instead, through the use of contemporary network approaches, Part II sets out the complexities of the cobalt supply chain's multi-scalar levels, the various roles played by firm and non-firm actors, and the variety of coordinating forces that influence the structure of the contemporary sector.

One limitation of the analysis in part II is its use of secondary data sources as it is not possible to ensure the accuracy of data from such sources. Nonetheless, every effort was made to use reliable sources. Firm- and country-level data analysed in chapter 5 was reproduced from Roskill reports. Additional data was collected through desk-based research. Roskill has produced reports on the cobalt sector since the 1970s and is an independent research company based in London. The company notes that while it makes every reasonable effort to ensure the veracity of the information presented in its reports, it cannot expressly guarantee the accuracy and reliability of the estimates, forecasts and conclusions contained within its reports. Because Roskill's reports were not published annually, and because many of the older reports did not split out production and consumption geographically, production data limitations constrained the temporal dimension of chapter 5 of this research. Were data available, a temporal dimension to the global production network analysis could have been included. This perceived deficiently was in part addressed in chapter 6 which explored changes to the cobalt supply chain over time through the lens of international trade. Trade data analysed in chapter 6 was sourced from Global Trade Tracker (GTT), which publishes authoritative, official trade data for 91 countries and facilitates analysis of trade flows for the countries whose data are not directly included. Its data are based on the Harmonized Commodity Description and Coding System and is reported in terms of value, quantity, and unit price, for both exports and imports. Again, the temporal dimension of analysis in chapter 6 was limited by the availability of trade data, although a ten-year time series for analysis was possible.

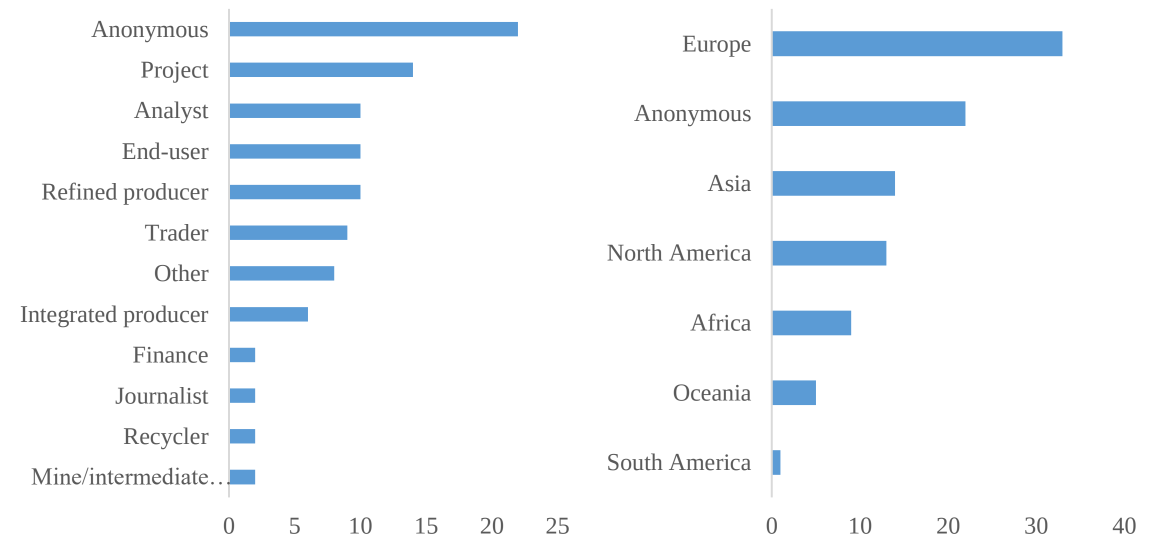
Methodologically, Part III made use of case studies, a cobalt-sector survey and semi-structured interviews and as such suffered from the methodological limitations typical of these methods (discussed in chapter 4). As the cobalt sector is secretive and opaque, the author used a mixture of qualitative research methods in an attempt to provide a deeper understanding of the cobalt supply chain.

While case studies served as a useful means of providing a detailed account of firm- and state-level responses to cobalt's criticality, they were limited insofar as they cannot be said to have created results that are relevant in all contexts. Their focus on two counties, the DRC and China, was appropriate given the importance of these states to the cobalt supply chain. However, by way of an example, the state-level responses to cobalt's critically illustrated in the DRC and China case studies of chapter 8, have little application to other states in the cobalt supply chain.

It was challenging to quantify at the outset what represented a meaningful and representative sample of survey respondents for the cobalt supply chain. How big is the cobalt supply chain? While the analysis in Part II set out 137 firms that produce cobalt in some form, numerous other end-users of cobalt (Apple, Tesla et. al) and various other intermediaries form part of the cobalt supply chain. From 466 email addresses of people with a known cobalt-sector interest, 97 respondents (21%) represents reasonable coverage. However, this approach meant that a high proportion of respondents were attendees of the Cobalt Institute's Annual Conference in Las Vegas, USA, 23-24th May 2018, which could be said to imply some selection bias. This appears more manifested in the geographic spread of known respondents than the spread of respondents' roles in the cobalt supply chain (Figure 8). Ultimately, the research (like all research) would have benefitted from a wider reach, but the author is confident that the survey population was a suitably meaningful and representative of the cobalt world.

Figure 51: Profile of cobalt-sector survey respondents

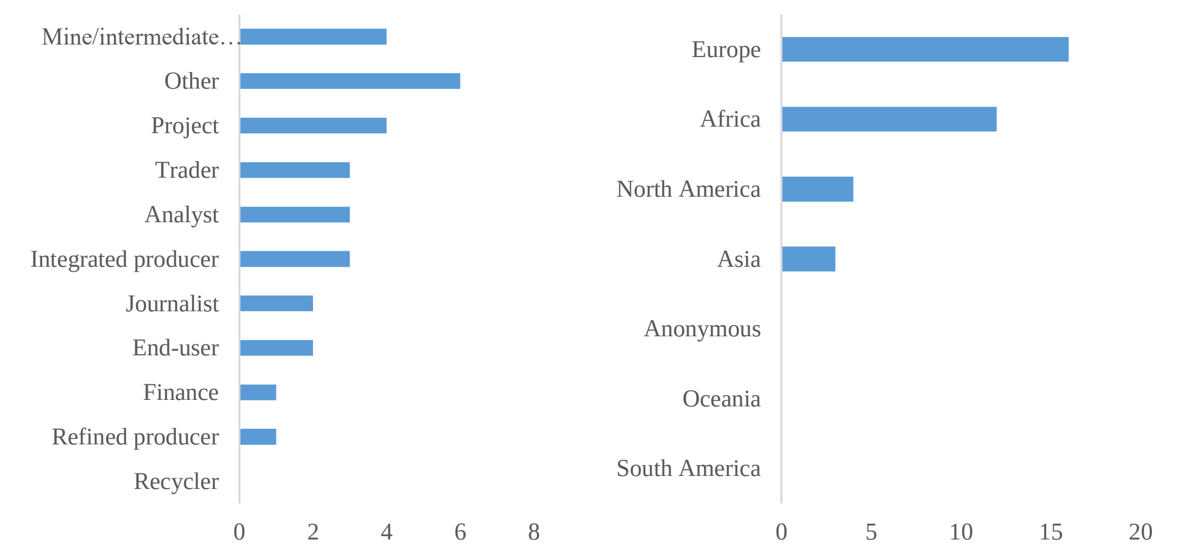
A suitable representative sample population for the cobalt sector survey should include responses from people engaged in the various stages of the supply chain and from all regions. In chapter 4, the following 12 groups were identified for different stages in the supply chain. The profiles of the 97 cobalt-sector respondents are shown below.



Similarly, a limitation of this research was the representative nature of the population that took part in semi-structured interviews. While there was a suitable spread of respondents from all stages of the cobalt supply chain (with the exception of recyclers) the geographical spread of respondents was heavily weighted towards African and European respondents. Again, the research would have benefitted from a wider reach. Unfortunately, and as anticipated, it was challenging to arrange interviews with actors in the secretive cobalt supply chain.

Figure 52: Profile of semi-structured interview respondents

A suitable representative sample population for semi-structured responses should include people engaged in the various stages of the supply chain and from all regions. The profiles of the 35 cobalt-sector respondents are shown below.



9.6 Policy implications and policy practise and regulation in the cobalt sector

Over the time it has taken to produce this dissertation, global interest in critical materials, and especially cobalt, has intensified. In the words of one interview respondent (R16) who has worked in the cobalt sector for decades:

"The whole dynamic of the cobalt market has changed…cobalt was a modest market, almost a curiosity metal, the paradigm shift now is immense because of the rapidity with which the electrification of mobility has taken place has completely changed the dynamics of the market. We are looking at a totally different market to three years ago. Totally different".

It isn't just cobalt's role in the electric vehicle revolution that has raised the metal's profile. Its concentration in the DRC and its association with child mining have elevated cobalt from curiosity metal to front-page story. An article on the cobalt supply chain was shown on the front page of the Wall Street Journal in September 2018 (Patterson and Wexler, 2018) and articles about cobalt are now commonplace in broadsheet publications. Much of this media attention is the result of the Amnesty International report, entitled: *This is what we die for*. Human rights abuses in the Democratic Republic of the Congo power the global trade in cobalt (Amnesty International, 2016). This, its follow up report, and other NGO publications have helped force the issue of raw material provenance into the public eye. There are now a wide range of sustainability agendas focused on the DRC, the wider metals industry and cobalt specifically (for some examples see: Cobalt Institute, 2019).

Attention on the wider critical materials agenda has also increased. In December 2017, President Donald Trump signed Presidential Executive Order on a federal strategy to ensure secure and reliable supplies of critical minerals. This set out plans to formulate a strategy to reduce US reliance on critical minerals; develop an assessment of progress toward developing critical minerals recycling and reprocessing technologies; explore technological alternatives to critical minerals; access and develop critical minerals through investment and trade; improve the topographic, geologic, and geophysical mapping of the USA; and make recommendations to streamline permitting and review processes related to developing leases (The White House, 2017). This document asserted that it shall be the policy of the US federal government to reduce the nation's vulnerability to disruptions in the supply of critical minerals; identify new sources of critical materials; and increase activity at all levels of the supply chain (The White House, 2017). In 2018, the US Department of the Interior published a list of 35 mineral commodities considered critical to the economic and national security of the United States. This list included cobalt (Federal Register, 2018).

This revised US critical material strategy was developed in the context of an escalating trade war between the USA and China. The USA imposed tariffs on billions of dollars' worth of Chinese products in 2018 with China following suit. These goods included many of the 35 mineral commodities considered critical to the economic and national security of the United States in the 2018 US Department of the Interior list. Tariffs on Chinese cobalt imports into the USA were set at 10% and were increased to 25% in May 2019, after bilateral trade talks between the USA and China broke down.

Elsewhere, Australia published a critical minerals strategy in 2019. This aims to enable the development of Australia's critical minerals sector, including downstream processing and manufacturing opportunities, by attracting investment, supporting innovation and connecting opportunities with infrastructure (Australian Government, 2019). The strategy is intended to support a vision to make Australia a world leader in the exploration, extraction, production and processing of critical minerals (Australian Government, 2019). Cobalt is listed as a critical material to Australia.

In Europe, a third list of critical raw materials was published in July 2017 by the European Commission (EC, 2017). The European Commission intends that the list should help to: strengthen the competitiveness of European industry in line with the renewed industrial strategy for Europe; stimulate the production of critical raw materials by enhancing new mining and recycling activities in the EU; foster efficient use and recycling of critical raw materials; increase awareness of potential raw material supply risks and related opportunities among EU countries; negotiate trade agreements, challenge trade distortion measures; develop research and innovation actions and implement sustainable development goals (EC, 2018).

As detailed at the start of this chapter, and in the introduction to this dissertation, a core motivation for this research is the contention that critical materials research has reached an impasse in recent years. It was argued that it was it important to advance the debate on critical materials beyond classification and definition, and to make policymakers and industry participants aware of the complex networks that underpin critical material production and consumption, how these networks are formed and coordinated, and the various firm and non-firm actors involved. Only in doing so, it was reasoned, can national-, regional-, industry- and firm-level strategies for ensuring raw material access be formulated and applied. What then, are the implications of this analysis for critical materials strategies and for policy, practise and regulation in the cobalt industry?

With reference to the EC (2018) priorities, the research can be used to increase awareness of potential raw material supply risks. Most critical material studies define supply risk in terms of the concentration of raw material mine production in one country. But concerns about cobalt supply risk shouldn't just relate to the high level of mine production in the DRC. This is an oversimplification and a broadening of the meaning of the term 'supply risk' is necessary. Cobalt supply risk should be considered in a more dynamic way, which takes into account the numerous stages of cobalt production and consumption, and the wide number of actors involved. Importantly, this research has identified other factors that should be considered as supply risks to cobalt end users. For example, the fact that industry consolidation has put a large concentration of production in the hands of a few Chinese firms and Glencore should be considered a risk. So too should the power that Gécamines holds over the DRC's most valuable mineral deposits. And so should the ever-increasing influence of the DRC and Chinese states. The term could also be widened to include corporate social responsibility risk and issues associated with raw material provenance.

With regard to negotiating trade agreements and challenging trade distortion measures (EC, 2018) this research can also be of some use. The ITN approach applied in chapter six highlighted the complexity of cobalt trade in all its forms, the changing patterns of international cobalt trade, and the relationships between the key actors involved. The research showed how international cobalt trade is increasingly characterised by Sino-Congolese trade. Further, it was shown how cobalt today is typically traded within the boundaries of the firm. In a period characterised by global trade wars to which commodities and critical materials are central, and in the post-Brexit era where trade agreement negotiation is to be front-page news, an understanding of the complexities of global of cobalt trade is valuable.

In terms of helping to address sustainable development goals (EC, 2018) it is hoped that the findings of this research will be of some use to important sustainability agendas. The application of a global production network approach to the cobalt supply chain, and thus the focus on the range of firm- and non-firm actors, should prove useful in identifying the various stakeholders involved. Importantly, the observations on the heterogeneity of actor types set out in this research should be of key consideration to those aiming to improve sustainability in the cobalt space. An understanding of the motivations of key actors in the cobalt supply chain, and how they react and respond to criticality and other underlying capitalist dynamics, may prove important when hoping to coerce diverse actors into meaningful sustainability actions.

While the focus of this dissertation was not on regional development outcomes, its focus on the DRC, and the scale of the challenges facing that country, prompt the following three suggestions for policy, practise and regulation related to the country's cobalt sector.

Firstly, corruption issues in the DRC must be addressed. This research argues that corruption in the DRC has, *inter alia*, limited the benefits of strategic coupling with global lead firms. As argued in the introduction, capturing value from natural resource endowments is highly important to economic development in some of the world's poorest regions. This isn't happening in the DRC. Firms undertaking FDI in the DRC should be further held to account by the international community and cobalt supply chain in terms of validation that their investments were legal, and that assets were purchased at market value. It is likely that this hasn't always been the case in recent years as shown in chapter 7 though the examination of Gécamines' and its privatisation of certain copper and cobalt assets. This could be improved by disclosure of mining agreements, contracts, and licenses and by the strengthening of supply chain compliance checks by consumers. Considerable efforts should be made to strengthen the benefits to local communities of cobalt GPNs touching down in their localities. This will require a reduction in corruption, stronger governance, and a willingness from local and national to champion the requirements of local actors when negotiating with lead firms.

Secondly, human rights issues in the DRC must be addressed. Child mining is still a feature of the cobalt supply chain. Responsibility for improving human rights conditions in the DRC is not just the responsibility of the international community. The cobalt supply chain and the international investment community have a key role to play in increasing responsible cobalt sourcing practices. The entire cobalt supply chain must insist on the use of only sustainable, verifiable, 'clean' cobalt and due-diligence initiatives must be adhered to. At the same time, pressure must continue to be placed on policymakers in the Congo. Without government-led intervention and strong governance in the DRC, child mining will remain a feature of the country.

Finally, the supply chain should strengthen its relationship with artisanal miners. Thousands of families depend on artisanal cobalt for their livelihoods and thus the creation of a sustainable cobalt supply chain that can utilise artisanally produced cobalt is of paramount importance. End users of cobalt should increase the level of scrutiny on artisanal cobalt in companies' supply chains to ensure that the DRC government is training, ensuring the safety of, and protecting the rights of artisanal cobalt miners. But, moreover, end users of cobalt should consider increased engagement with artisanal miners and work to improve their working practices and opportunities.

End-user strategies that advocate the avoidance of Congolese cobalt may serve to satisfy the corporate social responsibility agendas of the firm in question. But avoidance of DRC cobalt as means of risk mitigation won't help improve regional development outcomes for some of the world's poorest members of the cobalt supply chain. By virtue of geology, the DRC will always be an integral part of the cobalt supply chain and the source of most of the world's cobalt. It is thus the responsibility of the whole supply chain to ensure that issues such as corruption, human rights and worker rights are improved.

Appendix

This questionnaire will be used to help inform analysis as part of a PhD at the University of Cambridge. My research examines the changing patterns and underlying formation processes of critical materials supply chains focussing on cobalt as a case study. Focussing on the 2007 to 2017 period, the aim of the research is to determine how the cobalt supply chain is structured and organised, how its structure and organisation have evolved over time, how firms and states have responded to cobalt's "criticality" (supply risk, economic importance, and demand growth), and how these responses have resulted in spatial and structural outcomes.

Specifically, the questionnaire is intended to gather the views of market participants on how cobalt's "criticality" has affected the behaviours of firms and states. Your attitudes and opinions are critical to the success of my study. I recognise the value of your time, and sincerely appreciate your efforts on my behalf. Individual responses are **ANONYMOUS**, and all data will be held in **CONFIDENCE**. Please take 5 minutes to complete this survey return it to me at your earliest convenience. In return, I hope to produce a summary output from the research which I would be very happy to make available to you.

Key terms:

Critical materials – metals and minerals which are of high economic importance to a particular industry, sector or spatial area and are at risk of supply shortage.

Economic importance – reflects the importance of cobalt for end-use applications and the value added of corresponding manufacturing sectors.

Supply risk – reflects the risk of a disruption in supply of cobalt. In most critical materials studies, it is based on the concentration of primary supply from raw materials producing countries, considering their governance performance and trade aspects.

Resource nationalism – is defined as anti-competitive behaviour designed to restrict the international supply of a natural resource.

SECTION A – GENERAL QUESTIONS

Please indicate whether you agree with the following statements:

		Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
A1	By responding and reacting to “supply risk”, firms have altered the geographies of the cobalt supply chain	☐	☐	☐	☐	☐
A2	By responding and reacting to cobalt’s “economic importance”, firms have altered the geographies of the cobalt supply chain	☐	☐	☐	☐	☐
A3	States (and their governments) have played a significant role in shaping the geographies of the cobalt supply chain	☐	☐	☐	☐	☐

SECTION B – FOREIGN DIRECT INVESTMENT IN THE COBALT SECTOR

Please indicate whether you agree with the following statements:

		Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
B1	Concerns over “supply risk” have motivated firms to undertake foreign direct investment in cobalt assets	☐	☐	☐	☐	☐
B2	“Supply risk” is the *main* reason for firms having undertaken foreign direct investment in cobalt assets	☐	☐	☐	☐	☐
B3	“Economic importance” and expectations of future demand growth are *major* reasons for firms having undertaken foreign direct investment in cobalt assets	☐	☐	☐	☐	☐
B4	“Economic importance” and expectations of future demand growth are the *main*	☐	☐	☐	☐	☐

	reasons that firms have undertaken foreign direct investment in cobalt assets					
B5	Foreign direct investment in cobalt assets has increased over the past ten years because of concerns related to the future availability of economic cobalt resources	☐	☐	☐	☐	☐
B6	Foreign direct investment in cobalt assets has increased over the past ten years because of expectations regarding future demand of cobalt	☐	☐	☐	☐	☐
B7	Foreign direct investment in cobalt assets is principally driven by a firm's copper or nickel requirements	☐	☐	☐	☐	☐

SECTION C – INTEGRATION IN THE COBALT SUPPLY CHAIN

Please indicate whether you agree with the following statements:

		Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
C1	It is preferable for a refined cobalt producer to be fully integrated, rather than buy cobalt concentrates or intermediates	☐	☐	☐	☐	☐
C2	Concerns over "supply risk" have led refined producers of cobalt to integrate backwards, thus bringing supply of feedstock within the boundaries of the firm	☐	☐	☐	☐	☐
C3	Demand for cobalt and its "economic importance" has led some mine producers of cobalt to pursue production of higher-value cobalt products to capture more value	☐	☐	☐	☐	☐
C4	End-users (e.g. electronics/automotive OEMs) have become more involved with the procurement of the raw materials used	☐	☐	☐	☐	☐

	to produce the refined cobalt products that they consume in recent years					
C5	Mine producers have become increasingly more engaged with end users of cobalt in recent years	☐	☐	☐	☐	☐
C6	Firms are now more likely to undertake more than one stage of cobalt production (mine, intermediate, refined, etc.) than was the case a decade ago	☐	☐	☐	☐	☐
C7	The cobalt supply chain has become more consolidated over the past ten years	☐	☐	☐	☐	☐

SECTION D – The Democratic Republic of Congo

Please indicate whether you agree with the following statements:

		Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
D1	The DRC uses the threat of resource nationalism to maximise its revenues from its mining sector	☐	☐	☐	☐	☐
D2	The DRC uses the threat of resource nationalism to exercise control over foreign firms operating in its jurisdiction	☐	☐	☐	☐	☐
D3	The DRC Government is likely to introduce an export ban on unrefined cobalt over the next ten years	☐	☐	☐	☐	☐
D4	The DRC Government has been selective about which firms acquire or invest in its cobalt assets	☐	☐	☐	☐	☐
D5	Demand for cobalt and its “economic importance” has prompted the DRC Government to change its mining code	☐	☐	☐	☐	☐
D6	The revision of the DRC mining code is intended to increase the level of state	☐	☐	☐	☐	☐

	control over its mining sector and mining titles					
D7	The revision of the DRC mining code is intended to increase state revenues from the mining sector	☐	☐	☐	☐	☐
D8	The revision of the DRC mining code makes the country less attractive for foreign direct investment	☐	☐	☐	☐	☐
D9	The revision of the DRC mining code is intended to improve the social and environmental responsibility of mining companies operating in the country	☐	☐	☐	☐	☐

SECTION E – China

Please indicate whether you agree with the following statements:

		Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
E1	Demand for cobalt and its "economic importance" has led Chinese firms to aggressively acquire overseas mine assets	☐	☐	☐	☐	☐
E2	Chinese firms have invested heavily in the DRC in order to secure cobalt feedstock for Chinese refineries	☐	☐	☐	☐	☐
E3	Chinese investment in the DRC is actively encouraged by the Chinese Government	☐	☐	☐	☐	☐
E4	Chinese firms operating in the DRC are less likely to undertake socially and environmental responsible extraction	☐	☐	☐	☐	☐
E5	Chinese firms are more likely to source artisanally produced material than non-Chinese firms	☐	☐	☐	☐	☐
E6	Chinese control of DRC cobalt assets is likely to increase over the next ten years	☐	☐	☐	☐	☐

E7	Chinese end-users (e.g. electronics/automotive OEMS) have become more involved with the procurement of the raw materials used to produce the refined cobalt products that they consume in recent years	☐	☐	☐	☐	☐

SECTION F – Follow-up interview

		Yes	No
F1	Would you be happy to be contacted for a follow up interview?	☐	☐

Bibliography

Abbate, A. De Benedictis, L. Fagiolo, G. and Tajoli, L., 2012. The international trade network in space and time. *Laboratory of Economics and Management Working Paper Series*, 17(October), 1–32.

Academy of Finland, 2014. *Mineral resources and material substitution research programme.* [online] Available at: <http://www.aka.fi/Tiedostot/Tiedostot/Mineraalit/Mineraalivarat_Ohjelmamuistio_en.pdf> [Accessed 19 March 2014].

Achzet, B. and Helbig, C., 2013. How to evaluate raw material supply risks – an overview. *Resources Policy*, 38(4), 435–447.

Ackerman, E., 1953. Resources for freedom. *The American Academy of Political and Social Science,* 288(1), 172–175.

Afoaku, Osita., 2010. *Countries at the Crossroads 2010* - *Democratic Republic of Congo*. New York, NY: Freedom House.

Albert, R. and Barabasi, A., 2002. Statistical mechanics of complex networks. *Reviews of Modern Physics*. 74(January), 47–95.

Alonso, Elisa. Field, Frank. Gregory, Jeremy. and Kirchain, Randolph., 2007. Material availability and the supply chain: risks, effects, and responses. *Environmental Science and Technology,* 41(19), 6649–6656.

Alonso, W., 1964. *Location and land use*. Cambridge, MA: Cambridge University Press.

Amnesty International, 2016. *This is what we die for. Human rights abuses in the Democratic Republic of the Congo power the global trade in cobalt.* [online] Available at: <https://www.amnesty.org/en/documents/afr62/3183/2016/en/> [Accessed 29 April 2016].

Amnesty International, 2018. *Time to recharge. Corporate action and inaction to tackle abuses in the cobalt supply chain.* [online] Available at: <https://www.es.amnesty.org/uploads/media/Time_to_recharge_online_1411.pdf> [Accessed 2 September 2018].

Angerer G. Erdmann L. Handke V. Lullmann A. Marscheider-Weidemann F. Mawede M. and Scharp M., 2009. *Raw materials for emerging technologies, the influence of sector-specific feedstock demand on future raw materials consumption in material-intensive emerging technologies*. [online] Available at: <http://publica.fraunhofer.de/eprints/urn:nbn:de:0011-n-1115143.pdf> [Accessed 19 March 2014].

Arrow, K., 1970. *Essays in the theory of risk-bearing*. Amsterdam: Markham.

Assunção, S. Forte, R. and Teixeira, A., 2011. Location determinants of FDI: a literature review. FEP working papers 433. [online] Available at: <http://wps.fep.up.pt/wps/wp433.pdf > [Accessed 15 December 2016].

Athanassoulis, N. and Wilson, J., 2009. When is deception in research ethical? *Clinical Ethics*, 4(1), 44–49.

Arezki, Rabah, Sambit Bhattacharyya, and Nemera Mamo. ,2015. Resource discovery and conflict in Africa: What do the data show? Working paper, Centre for the Study of African Economies. [online] Available at: < http://sro.sussex.ac.uk/id/eprint/63531/> [Accessed 6 January 2020].

Australian Government Department of Industry, Innovation and Science (Australian Government) 2019. Australia's critical minerals strategy. [online] Available at: <https://www.industry.gov.au/sites/default/files/2019-03/australias-critical-minerals-strategy-2019.pdf> [Accessed 8th March 2020].

Auty, R., 1993. *Sustaining development in the mineral economies: the resource curse thesis*. London: Routledge.

Auty, R., 2001. *Resource abundance and economic development*. Oxford: Oxford University Press.

Auty, R. and Gelb, A., 2001. Political economy of resource abundant states. In: Auty, R. ed. 2001. *Resource abundance and economic development*. Oxford: Oxford University Press. 126–44.

Azadeh, A. and Alem, S. M., 2010. A flexible deterministic, stochastic and fuzzy data envelopment analysis approach for supply chain risk and vendor selection problem: simulation analysis. *Expert Systems with Applications*, 37(12), 7438–7448.

Bae, J-C., 2010. Strategies and perspectives for securing rare metals in Korea. In: MIT, 2010. *Critical elements for new energy technologies, an MIT energy initiative workshop report*. [online] Available at: <http://web.mit.edu/miteicomm/web/reports/critical_elements/CritElem_Report_Final.pdf> [Accessed 5 November 2015].

Bailey, K., 1994. *Methods of social research.* 4th edition. New York, NY: The Free Press.

Bair, Jennifer., 2009. Global commodity chains – genealogy and review. In: Jennifer Bair, ed. 2009. *Frontiers of commodity chain research*. Stanford, CA: Stanford University Press. 1–34.

Baldwin, R. Forslid, R. Martin, P. Ottaviano, G. and Robert-Nicound, F., 2003. *Economic geography and public policy*. Princeton, NJ: Princeton University Press.

Barney J., 1986. Strategic factor markets: expectations, luck and business strategy. *Management Science*, 32(10), 1231–1241.

Barney, J. and Ouchi, W., 1986. *Organisational Economics*. San Francisco, CA: Jossey-Bass.

Barrat, A., Barthelemy, M., and Vespignani, A., 2008. *Dynamical processes on complex networks*. New York, NY: Cambridge University Press.

Barigozzi, M. Fagiolo, G. and Garlaschelli, D., 2010. Multinetwork of international trade: a commodity-specific analysis. *Physical Review E*, 81(4), 046104.

BBC, 2011. Japan earthquake: Production halted at factories. *BBC*, [online] 11 March 2011. Available at: <http://www.bbc.com/news/business-12717260> [Accessed 5 November 2015].

Bedder, J. C. M., 2015. Classifying critical materials: a review of European approaches. *Applied Earth Science*, 124(4), 207–212.

Bell, S., 1996. *Learning with information systems: Learning cycles in information systems development*. New York, NY: Routledge.

Berger, Paul. D. Gerstenfeld, Arthur. and Zeng, Amy. Z., 2004. How many suppliers are best? A decision-analysis approach. *Omega*, 32(1), 9–15.

Benedictis, L. and Tajoli, L., 2011. The world trade network. *The World Economy*, 38(8), 1417–1454.

Bemard, H., 1988. *Research methods in cultural anthropology*. Newbury Park, CA: Sage.

Bevir, M., 2013. *Governance: A Very Short Introduction*. Oxford: Oxford University Press.

Bhattacharya K., Mukherjee G., and Manna, S.S. 2007. The International Trade Network. In: Chatterjee A. Chakrabarti B. K. eds. 2007. *Econophysics of Markets and Business Networks*. *New Economic Windows*. Milan: Springer. 139–147.

BHP Billiton, 2016. *Our history*. [online] Available at: <http://www.bhpbilliton.com/aboutus/ourcompany/ourhistory> [Accessed 22 July 2016].

Blechman, B. M. Sloss, D., 1985. *National security and strategic minerals: an analysis of U.S. dependence on foreign sources of cobalt*. Boulder, Co: Westview Press.

Blos, Mauricio F. Quaddus, Mohammed. Wee, H. M. and Watanabe, Kenji., 2009. Supply chain risk management (SCRM): a case study on the automotive and electronic industries in Brazil. *Supply chain management: an international journal*, 14(4), 247–252.

Bogataj, David. and Bogataj, Marija., 2007. Measuring the supply chain risk and vulnerability in frequency space. *International journal of production economics*, 108(1-2), 291–301

Brautigam, D., 2009. *The dragon's gift: the real story of China in Africa*. Oxford: Oxford University Press.

Bridge, G., 2008. Global production networks and the extractive sector. *Journal of Economic Geography*, 8(3), 389–419.

British Geological Survey (BGS), 2009. *Cobalt*. [online] Available at: <https://www.bgs.ac.uk/downloads/start.cfm?id=1400> [Accessed 18 January 2016].

British Geological Survey (BGS), 2011. *Risk list 2011*. [online] Available at: <http://www.bgs.ac.uk/mineralsuk/statistics/riskList.html> [Accessed 14 October 2014].

British Geological Survey (BGS), 2012. *Risk list 2012 – An update to the supply risk index for elements or element groups that are of economic value.* [online] Available at: <http://www.bgs.ac.uk/mineralsuk/statistics/riskList.html> [Accessed 14 October 2014].

Broadman, H. G., 2007. *Africa's silk road; China and India's new economic frontier*. Washington: The World Bank.

Bromley, D., 1990. Academic contributions to psychological counselling: 1. A philosophy of science for the study of individual cases. *Counselling Psychology Quarterly*, 3(3), 299–307.

Brookfield, H., 1977. Dissent from the periphery. In Ohlin, B. Hesselborn, P-E, and Wijkman, P. eds. 1977. *The international allocation of economic activity*. New York, NY: Holmes & Meier Publishers. 70–79.

Brunnschweiler, Christa N. and Bulte, Edward H., 2009. Natural resources and violent conflict: Resource abundance, dependence, and the onset of civil wars. *Oxford Economic Papers*, 61(4), 651–74.

Brülhart, M., 1998. Economic geography, industry location and trade: the evidence. World Economy, 21(6), 775–801.

Bryman, A. and Bell, E., 2007. *Business Research Methods, 2nd edition*. Oxford: Oxford University Press.

Bucheli, M., 2007. *The politics of vertical integration in extractive industry: business history and political economy, Working Paper, University of Illinois at Urbana-Champaign, College of Business*. [online] Available at: <http://business.illinois.edu/working_papers/papers/07-0112.pdf> [Accessed 18 August 2016].

Buchert, M. Schüler, D. and Bleher, D., 2009. *Critical metals for future sustainable technologies and their recycling potential, Öko-Institut, United Nations Environmental Programme*. [online] Available at: <http://www.oeko.de/oekodoc/1070/2009-129-en.pdf> [Accessed 5 November 2015].

Buckley, P. and Casson, M., 1976. *The future of the multinational enterprise*. London: Macmillan.

Buckley, P.J. Clegg, J.L. Cross, A.R. Voss, H. Rhodes, M, and P. Zheng. 2008. Explaining China's outward FDI: an institutional perspective. In: K.P. Sauvant, ed. 1984. *The rise of transnational corporations from emerging markets: threat or opportunity?* Northampton, MA: Edward Elgar Publishing Limited, 107–157.

Buijs, B. Sievers, H. and Espinoza, L., 2012. Limits to the critical raw materials approach. *Waste and Resource Management*, 165(WR4), 201–208.

Burnard, P., 1994. The telephone interview as a data collection method. *Nurse Education Today,* 14, 67–72.

Caldarelli, G., 2007. *Scale-free networks: complex webs in nature and technology*. Oxford: Oxford University Press.

Cavinato, J. L., 2004. Supply chain logistics risk: from the back room to the board room. *International Journal of Physical Distribution & Logistics Management*. 34(5), 383–387.

Chakhmouradian, A. R. Smith, M. P. and Kynicky, J. P., 2015. From "strategic" tungsten to "green" neodymium: a century of critical metals at a glance. *Ore Geology Reviews*, 64(1), 455–458.

Chandler, A., 1977. *The visible hand: the managerial revolution in American business*. Cambridge, MA: Harvard University Press.

Cheung, Yin-Wong. and Xingwang, Qian., 2009. The empirics of China's outward direct investment, *Pacific Economic Review*, 14(3), 312–341.

Choi, Thomas. Y. and Krause, Daniel. R., 2006. The supply base and its complexity: implications for transaction costs, risks, responsiveness, and innovation. *Journal of operations management.* 24(5), 637–652.

Christopher, Martin, 1992. *Logistics and supply chain management: strategies for reducing costs and improving services*. London: Pitman Publishing.

Christopher, Martin., and Towill, Denis. R. 2002. Developing market specific supply chain strategies. International Journal of Logistics Management, 13(1), 1–14.

Christopher, M. and Peck, H., 2004. Building the resilient supply chain. *International Journal of Logistics Management*, 15(2), 1–13.

Ciccantell, Paul. and Smith, David, A., Rethinking global commodity chains: integrating extraction, transport, and manufacturing. *International journal of comparative sociology*. 30 (3–4), 361–384.

Ciuriak, D. Lapham, B. and Wolfe, R., 2011. New-new trade policy. Queen's Economics Department, Working Paper 1263. [online] Available at: <http://qed.econ.queensu.ca/working_papers/papers/qed_wp_1263.pdf> [Accessed 5 November 2015].

Clark, G., 1998. Stylized facts and close dialogue: methodology in economic geography. *Annals of the Association of American Geographers*, 88(1), 73–87.

Clements, Kenneth W. and Johnson, Peter., 2000. The minerals industry and employment in Western Australia: assessing its impacts in federal electorates. *Resources Policy*, 26(2), 77–89.

Clowes, William. and Biesheuvel, Thomas. 2019. Glencore plans to shut giant cobalt and copper mine in Congo. *Bloomberg*. 6 August 2019. Available [online] at: <https://www.bloomberg.com/news/articles/2019-08-06/glencore-plans-to-shutter-giant-cobalt-and-copper-mine-in-congo> [Accessed 21 January 2020].

Coase, R., 1937. The nature of the firm. *Economica*, 4(16), 386–405.

Coase, R., 1960. The problem of social cost. *Journal of law and economics*, III(October), 1–44.

Cobalt Institute (CI), 2017. *About Cobalt*. [online] Available at: <https://www.cobaltinstitute.org/about-cobalt.html> [Accessed 18 August 2017].

Cobalt Institute (CI), 2019. *Sustainability*. [online] Available at: <https://www.cobaltinstitute.org/sustainability.html> [Accessed 2 April 2019].

Coe, N. Dicken, P. and Hess, M., 2008. Global production networks: realising the potential. *Journal of Economic Geography*, 8(3), 271–295.

Coe, N. M. and Yeung, Henry. Wai-Chung. 2015. Global production networks 2.0. In: Coe, N.M. and Yeung, Henry. Wai-Chung. eds. 2015. *Global production networks – theorizing economic development in an interconnected world.* Oxford: Oxford University Press.

Collier, P. and Hoeffler, A. 1998. On the economic causes of civil war, *Oxford Economic Papers*, 50(4), 563–73.

Commission of the European Communities (CEC), 1975. *The community's supplies of raw materials, communication from the Commission to the Council*. [online] Available at: <http://aei.pitt.edu/1481/1/raw_materials_COM_75_50.pdf.> [Accessed 14 October 2014].

Coulomb, Renaud. Dietz, Simon. Godunova, Maria. and Bligaard. Nielsen, Thomas. 2015. *Critical minerals today and in 2030, an analysis for OECD countries. OECD Environment Working Paper 91*. [online] Available at: <http://dx.doi.org/10.1787/5jrtknwm5hr5-en> [Accessed 6 November 2015].

Cousins, P.D. Lamming, R.C. and Bowen, F., 2004. The role of risk in environment-related supplier initiatives. *International Journal of Operations and Production Management*. 24(5-6) 554–565.

Critical Raw Materials Alliance (CRM Alliance), 2018. *CRM Alliance*. [online] Available at: <http://criticalrawmaterials.org/> [Accessed 17 March 2018].

Crang, M.A. Hughes, A. Gregson, N. Norris, L. and Ahamed F.U., 2013. Rethinking governance and value in commodity chains through global recycling networks. *Transactions of the institute of British geographers*, 38(1),12–24.

Creswell, J.W., 1994. *Research design: qualitative & quantitative approaches*. London: SAGE Publications.

Cronan, W., 1991. *Nature's metropolis: Chicago and the Great West*. New York, NY: Norton.

Cui, Sui. and Jingzhi, Ding., 2011. Business orientation of logistics development for state reserve warehouse in China. *Advances in Information Sciences and Service Sciences*, 3(6), 167–173.

Cui, L. and F. Jiang., 2012. State ownership effect on firms' FDI ownership decisions under institutional pressure: a study of Chinese outward investing firms. *Journal of International Business Studies*, 43(3), 264–284.

Cullbrand, K., and Magnusson, O. 2012. The use of potentially critical materials in passenger cars, Chalmers University of Technology, Report No: 2012:13. [online]. Available at: <http://www.criticalrawmaterials.eu/wp-content/uploads/D4-3-Transport-sector-report-FINAL.pdf> [Accessed 6 November 2015].

Cuvelier, Jeroen. Vlassenroot, Koen. and Olin, Nathaniel., 2014. Resources, conflict and governance: a critical review. Extractive Industries and Society 1(2), 340–50.

Daft, R., 1983. *Organization theory and design*. New York, NY: West Publishing.

Dalton, M., 1959. *Men who manage*. New York: Wiley.

Daniele, Vittorio. 2011. Natural Resources and the 'Quality' of Economic Development. *The Journal of Development Studies*. 47(4), 545–573.

Dasgupta, P. and Heal, G., 1974. The optimal depletion of exhaustible resources. *Review of Economic Studies*, 41(Symposium on the economics of exhaustible resources), 3–28.

Daviron, Benoit. and Ponte, Stefano., 2005. *The coffee paradox: global markets, commodity trade and the elusive promise of development*. London: Zed Books.

Davis, G. and Cordano, A., 2013. International trade in mining products. *Journal of economic surveys*, 27(1), 74–97.

Dawley, Stuart. MacKinnon, Danny. and Pollock, Robert., 2019. Creating strategic couplings in global production networks: regional institutions and lead firm investment in the Humber region, UK. *Journal of Economic Geography*, 9(4), 853–872.

Dawley, S., 2011. Transnational corporations and local and regional development. In Pike, A. Rodriguez-Pose, A. and Tomaney, J. J. eds. *Handbook of Local and Regional Development*. 394–412. London: Routledge. 394–412.

De Benedictis, L. and Tajoli, L., 2011. The world trade network. *The World Economy*, 34(8), 1417–1454.

Dean, H., 1971. Scarce resources: the dynamics of U.S. imperialism. In: Hodges, D. and Fann, K., eds. 1971. *Readings in U.S. imperialism.* Boston, MA: Porter Sargent. 139–154.

Deichmann, J. Karidis, S. and S. Sayek., 2003. Foreign direct investment in Turkey: regional determinants. *Applied Economics,* 35(16), 1767–78.

Deemster, H., 1967. Toward a theory of property rights. *American Economic Review*, 57(2), 347–359.

Derudder, Ben. and Witlox, Frank., 2010. Wold cities and global commodity chains: an introduction. In: Derudder, Ben. and Witlox, Frank. eds. 2010. *Commodity chains and world cities*. Chichester: Wiley-Blackwell. 1–14.

Dicken, P. Kelly, P. Olds, K. and Yeung, H. W-C., 2001. Chains and networks territories and scales: towards an analytical framework for the global economy. *Global Networks*, 1(2), 89–112.

Dicken, P., 2011. *Global shift: mapping the changing contours of the world economy*. London: Sage.

Domjan, P. and Stone, M., 2010. A comparative study of resource nationalism in Russia and Kazakhstan 2004–2008. *Europe-Asia Studies*, 62(1), 35–62.

Dougherty, Michael., 2013. The global gold mining industry: materiality, rent-seeking, junior firms and Canadian corporate citizenship. *Competition and change*, 17(4), 339–54.

Drysdale, Peter. and Findlay, Christopher., 2009. Chinese foreign direct investment in Australia: policy issues for the resource sector. *China Economic Journal*, 2(2), 133–158.

Duclos, S. J. Otto, J. P. Konitzer, G. K., 2010. Design in an era of constrained resources. *Mechanical Engineering*, 132(9), 36–40.

Dunning, J., 1971. *The multinational enterprise*. London: Allen and Unwin.

Dunning, J., 1979. Explaining changing pattern of international production: in defence of eclectic theory. *Oxford bulletin of economics and statistics*, 41(4), 269–296.

Dunning, J., 1988. *Explaining international production*. London: Unwin Hyman.

Dunning, J., 1993. *Multinational enterprises and the global economy*. Boston, MA: Addison-Wesley.

Dunning, J. H., 2006. Comment on Dragon multinationals: new players in 21st century globalization. *Asia Pacific Journal of Management*, 23(2), 139–141.

Dutch Ministry of Foreign Affairs, 2011. Policy document on raw materials. [online] Available at: <http://ec.europa.eu/enterprise/policies/rawmaterials/files/docs/mss-netherlands_en.pdf> [Accessed 19 March 2014].

Ellis, Scott. C. Henry, Raymond. M. and Shockley, Jeff., 2010. Buyer perceptions of supply disruption risk: a behavioural view and empirical assessment. *Journal of operations management*, 28(1), 34–46.

Elshamy, Hamy. M. 2015. The economic determinants of Chinese foreign direct investment in Egypt. *Journal of Chinese Economic and Foreign Trade Studies*, 8(1), 20–26.

Engelbert, E. A. 1953. Resources and the nation's future: review of resources for freedom by President's materials policy commission. Public Administration Review, 13(1), 53–57.

Erdmann, Lorenz. and Graedel, Thomas. E., 2011. Criticality of non-fuel minerals: a review of major approaches and analyses. *Environmental Science and Technology*, 45(18), 7620–7630.

Erickson, F., 1986. Qualitative methods in research on teaching. In: Whittrock, M. ed. 1986. *Handbook of research on teaching.* 3rd edition. Old Tappan, NJ: Macmillan, 119-161.

European Commission (EC), 2010. *Critical raw materials for the EU – Report of the ad–hoc working group on defining critical raw materials*. Brussels: EC. [online] Available at: <https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/system/files/ged/79%20report-b_en.pdf> [Accessed 21 February 2017].

European Commission (EC), 2014. *Report on critical raw materials for the EU – Report of the ad–hoc working group on defining critical raw materials*. Brussels: EC. [online] Available at: < https://ec.europa.eu/docsroom/documents/10010/attachments/1/translations/en/.../pdf> [Accessed 21 February 2017].

European Commission (EC), 2015. *Report on critical raw materials for the EU – critical raw materials profiles.* Brussels: EC. [online] Available at: <https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en> [Accessed 21 February 2017].

European Commission (EC), 2017. *Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the 2017 list of critical raw materials for the EU*. Brussels: EC. [online] Available at: <https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=CELEX:52017DC0490> [Accessed 21 May 2019].

European Commission (EC), 2018. *Critical Raw Materials*. [online] Available at: <http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en> Accessed 2 April 2019].

EY, 2018. *Global tax alert: Democratic Republic of Congo reforms mining code*. [Online] Available at: <https://www.ey.com/Publication/vwLUAssets/Democratic_Republic_of_Congo_reforms_Mining_Code/$FILE/2018G_02215181Gbl_Democratic%20Republic%20of%20Congo%20reforms%20Mining%20Code.pdf> [Accessed 16 July 2018].

Fang, Jiarui. Zhao, Lei. Fransoo, Jan. C. and Van Woensel, Tom., 2013. Sourcing strategies in supply risk management: an approximate dynamic programming approach. *Computers & operations research*, 40(5), 1371–1382.

Federal Ministry of Economics and Technology, 2010. *The German Government's raw materials strategy – safeguarding a sustainable supply of non-energy resources for Germany*. [online] Available at: < http://www.bmwi.de/English/Redaktion/Pdf/raw-materials-strategy,property=pdf,bereich=bmwi2012,sprache=en,rwb=true.pdf> [Accessed 19 March 2014].

Federal Register, 2017. Executive Order 13817. A federal strategy to ensure secure and reliable supplies of critical minerals. 82 FR 60835. December 26 2017. [online] Available at: <https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals> [Accessed 2 April 2019].

Federal Register, 2018. Final list of critical minerals 2018. 83 FR 23295. May 18 2018. [online] Available at: <https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018> [Accessed 2 April 2019].

Fernandez, M. Prieto, J. and Hidalgo, C. 2011. A complex network approach to international commodity trade markets. *International Journal of Complex Systems in Science,* 1(2), 191–201.

Finan, P., 2018. *A new mining code for the DRC*. DLA Piper. [online] Available at: <https://www.dlapiper.com/en/morocco/insights/publications/2018/08/democratic-republic-of-congo-mining-code/> [Accessed 10 March 2018].

Fine, B. and Leopold, E., 1993. *The world of consumption*. London: Routledge.

First Quantum Minerals (FQM), 2018. *History*. [online] Available at: <https://www.first-quantum.com/Our-Company/history/default.aspx> [Accessed 3 September 2018].

Forbes, 2019. *#1818 Dan Gertler*. [online] Available at: < https://www.forbes.com/profile/dan-gertler/#5b219f74348d> [Accessed 29 April 2019].

Fowler, J. and Floyd, J., 1995. *Improving survey questions: design and evaluation: 038*. Thousand Oaks, CA: Sage Publications.

Friedland, William, H., 1984. Commodity systems analysis: an approach to the sociology of agriculture. In: Schwarzweller, Harry, K. ed. 1984. *Research in rural sociology and development*. London: JAI Press, 221–235.

Furubotn, E. and Pejovich, S., 1972. Property rights and economic theory: a survey of recent literature. *Journal of economic literature*, 10(4), 1137—1162.

Gaburro, Giuseppe. and O'Boyle, Edward., 2003. Norms for evaluating economic globalization. *International Journal of Social Economics*, 30, (1/2), 95–118.

Gachechiladze, M. and Staddon, C., 2007. Towards a political ecology of oil in post-communist Georgia: the conflict over the Kulevi oil port development. *Journal of Political Ecology*, 14(1), 58–75.

Garton, L. Haythornthwaite, C. and Wellman, B., 1999. Studying on-line social networks. In: Jones, S. ed. *Doing internet research: critical issues and methods for examining the net*. 1999. Thousand Oaks, CA: Sage. 75–105.

Geological Survey of Finland, 2010. *Finland's mineral strategy*. [online] Available at: <http://projects.gtk.fi/export/sites/projects/minerals_strategy/documents/FinlandsMineralsStrategy_2.pdf> [Accessed 19 March 2014].

Gereffi, Gary., 1994. The organization of buyer-driven global commodity chains: how U.S. retailers shape overseas production networks. In: Gereffi, G. and Korzeniewicz, M., eds. 1994. *Commodity chains and global capitalism*. Westport, CT: Praeger. 95–122.

Gereffi, G. Korzeniewicz, M. and Korzeniewicz, R., 1994. Introduction: global commodity chains. In: Gereffi, G. and Korzeniewicz, M., eds. *Commodity chains and global capitalism*, CT: Praeger. 1–14.

Gereffi, Gary., 1995. Global production systems and third world development. In: Stallings, Barbara., ed. 1995. *Global change, regional response: the new international context of development*. Cambridge: Cambridge University Press. 100–142.

Gereffi, Gary. Humphrey, John. and Sturgeon, Timothy., 2005. The governance of global value chains. *Review of International Political Economy*, 12(1), 78–104.

Gibson, C. and Warren, A., 2016 Resource-sensitive global production networks: reconfigured geographies of timber and acoustic guitar manufacturing. *Economic Geography*, 92(4), 430–454.

Gilland, B., 2013. Considerations on world population and food supply. *Population and Development Review*, 9(2), 203–211.

Gillham, B., 2005. *Research interviewing: the range of techniques*. Berkshire: Open University Press.

Glasgow, Priscilla, A., 2005. *Fundamentals of survey research methodology*. Mitre: Washington C3 Center McLean, Virginia. [online] Available at: <https://www.mitre.org/sites/default/files/pdf/05_0638.pdf> [Accessed 29 April 2018].

Glencore, 2019. Ask Glencore: Democratic Republic of Congo. Available [online] at: <https://www.glencore.com/ask-glencore/democratic-republic-of-the-congo> [Accessed 21 January 2020].

Global Witness, 2004. R*ush and ruin – the devastating mineral trade in southern Katanga, DRC*. [online] Available at: <http://www.kongo-kinshasa.de/dokumente/ngo/gw_0904en.pdf> [Accessed 29 April 2016].

Global Witness, 2009. *Natural resource exploitation and human rights in the Democratic Republic of Congo 1993 to 2003*. London: Global Witness.

Global Witness, 2011. The Dodd Frank Act's section 1502 on conflict minerals. Briefing document August 10th, 2011. [online]. Available at: < https://www.globalwitness.org/en-gb/archive/dodd-frank-acts-section-1502-conflict-minerals/> [Accessed 6th January 2020].

Global Witness, 2016. Out of Africa – British offshore secrecy and Congo's missing $1.5 billion. [online] Available at: < file:///C:/Users/Jack/Downloads/Out_Of_Africa_final_EN.pdf> [Accessed 3 September 2018].

Glöser, Simon. Tercero Espinoza, Luis. Gandenberger, Carsten. and Faulstich. Martin., 2015. Raw material criticality in the context of classical risk assessment. *Resources Policy*, 44(June), 35–46.

Gluckler, J., 2007. Economic geography and the evolution of networks. *Journal of Economic Geography*, 7(5), 619–634.

Goh, Mark. Lim, Joseph. Y. S. Meng, Fanwen., 2007. A stochastic model for risk management in global supply chain networks. *European Journal of Operational Research*, 182(1), 164–173.

Goldin, Ian. and Mariathasan, Mike., 2015. *The butterfly defect – how globalization creates systemic risks, and what to do about it*. Princeton, NJ: Princeton University Press.

Gorard, S., 2002. Ethics and equity: pursuing the perspective of non-participants. *Social Research Update*, 39(Winter), 1–4.

Graedel, T.E. Barr, Rachel. Chandler, Chelsea. Chase, Thomas. Choi, Joanne. Christoffersen, Lee. Friedlander, Elizabeth. Henly, Claire. Jun, Christine. Nassar, Nedal T. Schechner, Daniel. Warren, Simon. Yang, Man-yu. and Zhu, Charles., 2011. Methodology of metal criticality determination. *Environmental Science and Technology*, 46(2), 1063–1070.

Graedel, T. E. Harper, E. M. Nassar, N. T. Nuss, Philip. and Reck, Barbera. K., 2015. Criticality of metals and metalloids. *PNAS*, 112(14), 4257–4262.

Gray, D., 2004. *Doing research in the real world*. London: Sage.

Greene, J. Caracelli, V. and Graham, W., 1989. Toward a conceptual framework for mixed-method evaluation designs. *Educational evaluation and policy analysis*, 11(3), 255–74.

Grossman, S. and Hart, O., 1986. The costs and benefits of ownership: a theory of vertical and lateral integration. *Journal of political economy*, 94(4), 691–719.

Guba, E. and Lincoln, Y., 1981. *Effective evaluation*. San Francisco, CA: Jossey-Bass.

Guenther, Bruce., 2008. The Asian drivers and the resource curse in Sub-Saharan Africa: the potential impacts of rising commodity prices for conflict and governance in the DRC. *The European Journal of Development Research*. 20(2), 347–363

Guertler, Benjamin. and Spinler, Stefan., 2015. Supply risk interrelationships and the derivation of key supply risk indicators. *Technological Forecasting and Social Change*, 92(March), 224–236.

Haber, S. and Menaldo, V., 2011. Do natural resources fuel authoritarianism? A reappraisal of the resource curse, *American Political Science Review*, 105(1), 1–26.

Haberler, G., 1977. Survey of circumstances affecting the location of production and international trade as analysed in the theoretical literature. In: Ohlin, B. Hesselborn, P-E. and Wijkman, P. eds. 1977. *The international allocation of economic activity*. New York, NY: Holmes & Meier Publishers. 1–24.

Haggett, P. and Chorley, R., 1972. *Network analysis in geography*. London: Arnold.

Hall, R. B., 1940. American raw-material deficiencies and regional dependence. *Geographical Review*, 30 (2), 177–186.

Hallikas, Jukka. Karvonen, Iris. Pulkkinen, Urho. Virolainen, Veli-Matti. and Tuominen, Markku., 2004. Risk management processes in supplier networks. *International Journal of Production Economics*, 90(1), 47–58.

Hao, Han. Ou, Xunmin. Du, Jiuyu Wang, Hewu. and Ouyang, Minggao., 2014. China's electric vehicle subsidy scheme: rationale and impacts. *Energy Policy*, 73(October), 722–732.

Harland, C. Brenchley, R. and Walker, H., 2003. Risk in supply networks. *Purchasing and Supply Management*. 9(2), 51–62.

Harper E. M. Kavlak G. Burmeister L. Eckelman M. J. Erbis S. Espinoza V. S. Nuss P. Graedel T. E., 2014. Criticality of the geological zinc, tin, and lead family. *Journal of Industrial Ecology*, 19(4), 628–644.

Harper E.M. Diao Z. Panousi S. Nuss P. Eckelman M.J. Graedel T.E., 2015. The criticality of four nuclear energy metals. *Resources, Conservation and Recycling*. 95, 193–201.

Hayes, S. and McCollough, E., 2018. Critical minerals: a review of elemental trends in comprehensive criticality studies. *Resources Policy*, 59, 192–199.

Helpman, Elhanan. Melitz, Marc. and Yeaple, Stephen. 2004. Export versus FDI with heterogeneous firms. *American Economic Review*, 94(1), 300–316.

Helpman, Elhanan., 2011. *Understanding global trade*. Cambridge, MA: The Belknap Press of Harvard University Press.

Henderson, J. Dicken, P. Hess, M. Coe, N. M. and Yeung, H. W-C., 2002. Global production networks and the analysis of economic development. *Review of International Political Economy*, 9(3), 436–64.

Henderson, J. Dicken, P. Hess, M. Coe, N. and Yeung, H., 2004. Global production networks and the analysis of economic development. *Review of International Political Economy*, 9(3), 436–64.

Herb, M., 2005. No representation without taxation? Rents, development and democracy, *Comparative Politics*, 37(3), 297–317.

Hitchcock, G. and Hughes, D., 1989. *Research and the teacher: a qualitative introduction to school-based research.* London: Routledge.

HM Government Horizon Scanning Programme (HMHSP), 2014. *Resource Nationalism*. [online] Available at: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/389085/Horizon_Scanning_-_Resource_Nationalism_report.pdf> [Accessed 4 September 2018].

Ho, William. Zheng, Tian. Yildiz, Hakan. and Talluri, Srinivas., 2015. Supply chain risk management: a literature review. *International journal of production research,* 53(16), 5031–5069.

Hogg, Jonny., 2013. Congo bans exports of copper, cobalt concentrates. Reuters, [online] 17 April. Available at: <https://uk.reuters.com/article/congo-democratic-copper-idUSL5N0D437H20130417> [Accessed 16 July 2018].

Holden, C., 1981. Getting serious about strategic minerals. *Science*, 212 (4492), 305–307.

Holton, R., 2008. *Global Networks*. London: Palgrave MacMillan.

Hopkins, T. and Wallerstein, I., 1977. Patterns of development of the modern world-system. *Review*, 1(2), 11–145.

Hopkins, Terence. K. and Wallerstein, Immanuel., 1986. Commodity chains in the world-economy prior to 1800. *Review*, 10(1), 157–170.

Hopkins, T. K. and Wallerstein, I., 1994. Commodity chains: construct and research. In: Gereffi, G., and Korzeniewicz, M. eds. 1994. *Commodity chains and global capitalism*. Westport, CT: Praeger. 17–20.

Horner, Rory., 2014. Strategic decoupling, recoupling and global production networks: India's pharmaceutical industry. *Journal of Economic Geography*, 14 (2014),1117–1140.

Hotelling, H., 1929. Stability in competition. *Economic Journal*, 39(153), 41–57.

Hotelling, H., 1931. The economics of exhaustible resources. *The Journal of Political Economy*, 39(2), 137–175.

House of Commons Science and Technology Committee, 2011. Strategically important metals. [online] Available at: <http://www.publications.parliament.uk/pa/cm201012/cmselect/cmsctech/726/726.pdf> [Accessed 19 March 2014].

Huayou Cobalt, 2015. *Corporate Social Responsibility Report 2015*. [online] Available at: <http://en.huayou.com/downloadRepository/d06604a9-02b8-497a-a5a1-b8559058b3c8.pdf> [Accessed 28 August 2018].

Huayou Cobalt, 2016. Corporate Social Responsibility Report 2016. [online] Available at:<http://en.huayou.com/downloadRepository/33ad0043-b857-4181-9c0a-fb4c9057d057.pdf> [Accessed 28 August 2018].

Huayou Cobalt, 2017. Corporate Social Responsibility Report 2017. [online] Available at:< http://en.huayou.com/downloadRepository/420fca72-ea59-4640-8ea5-66ddb1ec0f82.pdf> [Accessed 28 August 2018].

Hubbert, M. K., 1949. Energy from fossil fuels. *Science*, 109(2823), 103–109.

Hubert, André-Dumont., 2007. Disputes and their resolution under the mining code 2002 of the Democratic Republic of Congo. *Journal of Energy & Natural Resources Law*, 25(4), 351–374.

Hudson, R., 2008. Cultural political economy meets global production networks: a productive meeting? *Journal of Economic Geography*, 8(3), 421–40.

Hughes, Alex. and Reimer, Suzanne., 2004. Introduction. In: Hughes, Alex. and Reimer, Suzanne. eds. *Geographies of commodity chains*. 2011. New York, NY: Routledge. 1–17.

Hunter, L. M. Kasouf, C. J. Celuch, K. G. and Curry, K. A.; 2004. A classification of business-to-business buying decisions: risk importance and probability as a framework for e-business benefits. *Industrial Marketing Management*, 33(2), 145–154.

Humphreys, D., 2013. Long-run availability of mineral commodities. *Mineral Economics*, 26(1-2), 1–11.

Hymer, S., 1976. *The international operations of national firms, a study of foreign direct investment*. Cambridge, MA: MIT Press.

Innis, H., 1956. *The fur trade in Canada: an introduction to Canadian economic history*. University of Toronto Press: Toronto.

International Monetary Fund (IMF), 2007. *World economic outlook: Globalization and inequality*. [online] Available at: <http://www.imf.org/external/pubs/cat/longres.aspx?sk=20354> [Accessed 7 July 2016].

International Monetary Fund (IMF), 2019. Democratic Republic of Congo Selected Issues. IMF Country Report No. 19/286. [online] Available at: <https://www.imf.org/en/Publications/CR/Issues/2019/09/04/Democratic-Republic-of-the-Congo-Selected-Issues-48649> [Accessed 6 January 2020].

Irvine, Annie. Drew, Paul. and Sainsbury, Roy., 2012. ‘Am I not answering your questions properly?’ Clarification, adequacy and responsiveness in semi-structured telephone and face-to-face interviews. *Qualitative Research*, 13 (1), 87–106.

IZT and Adelphi, 2010. *Kritische Rohstoffe fur Deutschland – Identifikation aus sicht deutscher unternehmen wirtschaftlich bedeutsamer mineralischer rohstoffe, deren versorgungslage sich mittel – bis langfristig also kritisch erweisen konnte*. [online] Available at: <https://www.izt.de/fileadmin/downloads/pdf/54416.pdf> [Accessed 5 November 2015].

Jackson. P. Ward, N. and Russell, P., 2006. Mobilising the commodity chain concept in the politics of food and farming. *Journal of Rural Studies*, 22(2), 129–141.

Jacobs, W. and Lagendijk, A., 2014. Strategic coupling as capacity: how seaports connect to global flows of containerised transport. *Global Networks*, 14(1), 44–62.

James, Nadine., 2018. Resource nationalism on the rise in sub-Saharan Africa. *Creamer Mining Weekly*, [online] 15 June. Available at: < http://www.miningweekly.com/article/resource-nationalism-on-the-rise-in-sub-saharan-africa-2018-06-15-1> [Accessed 11th December 2018].

Jansson, Johanna., 2013. The Sicomines agreement revisited: prudent Chinese banks and risk-taking Chinese companies. *Review of African political economy*, 40(135), 152–162.

Jensen, M. C. and Meckling, W. H., 1976. Theory of the firm: managerial behavior, agency costs, and ownership structure. *Journal of Financial Economics*, 3(4), 305–360.

Jevons, W. S., 1865. *The coal question; an inquiry concerning the progress of the nation, and the probable exhaustion of our coal mines*. [e-book] Available at: <http://books.google.co.uk/books?id=gAAKAAAAIAAJ&pg=PA22&source=gbs_toc_r&cad=4#v=onepage&q&f=false> [Accessed 5 February 2013].

Joffe, G. Stevens, P. George, T. Lux, J. and Searle, C., 2009. Expropriation of oil and gas investments: historical, legal and economic perspectives in a new age of resource nationalism. *The Journal of World Energy Law & Business*, 2(1), 3–23.

Johns, J., 2006. Video games production networks: value capture, power relations and embeddedness. *Journal of economic geography*, 6 (1), 151–180.

Jones, G. K., 1988. United States dependence on imports of four strategic and critical minerals: implications and policy alternatives. *Boston College Environmental Affairs Law Review*, 15(2), 217–294.

Jopson, Barney., 2009. Chinese copper entrepreneurs flee DR Congo. *Financial Times*, [online] 19 February. Available at: <https://www.ft.com/content/e9d37ec8-feb8-11dd-b19a-000077b07658> [Accessed 15 July 2018].

Joskow, P. L., 2008. Vertical Integration. In: Ménard, C. and Shirley, M. eds. 2008. *Handbook of new institutional economics*. Berlin: Springer-Verlag Berlin Heidelberg. 789-811.

Jüttner, U., 2005. Supply chain risk management: understanding the business requirements from a practitioner perspective. *International Journal of Logistics Management*, 16(1), 120–141.

Jüttner, U. Peck. H., and Christopher, M. 2003. Supply chain risk management: outlining an agenda for future research. *International journal of logistics: research and applications*, 6(4), 197–210.

Kahneman, D. and Tversky, A., 1979. Prospect theory: an analysis of decision under risk. *Econometrica*, 47(2), 263–291.

Kaplinsky, R. and Messner, D., 2008. Introduction: The impact of the Asian drivers on the developing world. *World Development Special Issue on Asian Drivers and their Impact on Developing Countries*, 36(2), 197–209.

Kaplinsky R. and Morris M., 2009. Chinese FDI in sub-Saharan Africa: engaging with large dragons. *European Journal of Development Research*, 21(4), 551–569.

Karl, T., 1997. *The paradox of plenty: oil booms and petro-states*. Berkeley: University of California Press.

Kaup, B. and Gellert, P., 2017. Cycles of resource nationalism: hegemonic struggle and the incorporation of Bolivia and Indonesia. *International Journal of Comparative Sociology*, 58(4), 275–303.

Kelly, Annie. 2019. Apple and Google named in US lawsuit over Congolese child cobalt mining deaths. *The Guardian*. 16 December 2019. Available [online] at: <https://www.theguardian.com/global-development/2019/dec/16/apple-and-google-named-in-us-lawsuit-over-congolese-child-cobalt-mining-deaths> [Accessed 21 January 2020].

Kim, J. and Mahoney, J., 2005. Property rights theory, transaction costs theory, and agency theory: an organisational economics approach. *Managerial and decision economics*, 26(4), 223–242.

Kleibert, J. M., 2013. Strategic coupling in ‘next wave cities’: local institutional actors and the offshore service sector in the Philippines. *Singapore Journal of Tropical Geography*, 35(2014), 245–260.

Kleindorfer, Paul. R. and Saad, Germaine. H., 2009. Managing disruption risks in supply chains. *Production and Operations Management*, 14(1), 53–68.

Klimek, P. Obersteiner, M. and Thurner, P., 2015. Systemic trade risk of critical resources. *Science Advances*, 1(10): e1500522 DOI: 10.1126/sciadv.1500522

Kolstad, Ivar. and Arne, Wiig., 2009. *What determines Chinese outward FDI?* CMI Working Paper 2009(3). [online] Available at: < https://www.cmi.no/publications/3332-what-determines-chinese-outward-fdi> [Accessed 5 February 2018].

Konings, Piet., 2007. China and Africa: Building a strategic partnership. *Journal of Developing Societies*, 23(3), 341–367.

Knierzinger, Johannes., 2018. *Bauxite Mining in Africa: Transnational corporate governance and development*. London: Palgrave MacMillan.

Kraljic, P., 1983. Purchasing must become supply management. *Harvard Business Review*, 61(5), 109–117.

Kraemer, K. L., 1991. Introduction. In: Kraemer, K.L ed. *The information systems research challenge: Survey research methods*. Volume 3. Cambridge, MA: Harvard Business School.

Krautkraemer, J. A., 1998. Non-renewable resource scarcity. *Journal of Economic Literature*, 36(4), 2065–2107.

Krugman, P., 1991. Increasing returns and economic geography. *The journal of political economy*, 99(3), 483–499.

Krugman, P., 2009. The increasing returns revolution in trade and geography. *American Economic Review*, 99(3), 561–571.

Kudelko, J., 2013. Economic evaluation of mineral extraction projects from fields of exploitation during operational periods. *Mineral Economics*, 25(2), 77–82.

Kumar, Sri Krishna. Tiwari, M. K. and Babiceanu, Radu F., 2010. Minimisation of supply chain cost with embedded risk using computational intelligence approaches. *International journal of production research*, 48(13), 3717–3739.

Lafontaine, F. and Slade, M., 2007. Vertical integration and firm boundaries: the evidence. *Journal of Economic Literature*, 45(3), 629–685.

Lancaster, K., 1980. Intra-industry trade under perfect monopolistic competition. *Journal of International Economics*, 10(2), 151–175.

Landry, David. 2018. *The risks and rewards of resource-for-infrastructure deals: lessons from the Congo's Sicomines agreement.* China Africa Research Initiative Working Paper 16. [online] Available at: < https://static1.squarespace.com/static/5652847de4b033f56d2bdc29/t/5afb2521562fa7054be96c8b/1526408481701/Sicomines-working+paper-Landry+-v6.pdf> [Accessed 3 September 2018].

Lavrakas, P. J., 2008. *Encyclopaedia of survey research methods*. Thousand Oaks, CA: Sage Publications.

Le Billon, P., 2012. *Wars of plunder, conflicts, profits and the politics of resources*. London: Hurst & Company.

Lee, B. Preston, F. Kooroshy, J. Bailey, R. and Lahn, G., 2012. *Resources futures*. London: Chatham House.

Legard, R. Keegan, J. and Ward, K., 2003. In-depth interviews. In: Ritchie. J. Lewis, J. eds. 2003. *Qualitative research practice: A guide for social science students and researchers*. London: Sage. 138–169.

Leyshon, A., 1998. Geographies of money and finance III. *Progress in Human Geography*, 22(3), 433–446.

Li, Jian. Wang, Shouyang. and Cheng, T. C. E., 2010. Competition and cooperation in a single-retailer two-supplier supply chain with supply disruption. *International journal of production economics*, 124(1), 137–150.

Lin, Yong. and Zhou, Li., 2011. The impacts of product design changes on supply chain risk: a case study. *International journal of physical distribution & logistics management*, 41(2), 162–186.

Llieva, J. Baron, S. & Healey, N. M., 2002. Online surveys in marketing research: pros and cons. *International Journal of Market Research*, 44(3), 361–367.

Luo., Y. Xue, Q. and B. Han., 2010. How emerging market governments promote outward FDI: experience from china. *Journal of World Business*, 45(1), 68–79.

MacKinnon, Danny., 2012. Beyond strategic coupling: reassessing the firm-region nexus in global production networks. *Journal of Economic Geography*, 12(1), 227–245.

MacKinnon, Danny., 2013. Strategic coupling and regional development in resource economies: the case of the Pilbara. *Australian Geographer*, 44:3, 305–321.

MacNamara, W. and Thompson, C., 2010. Congo seizes First Quantum Minerals' assets. *Financial Times* [online] 31 August. Available at: < https://www.ft.com/content/27d6e104-b530-11df-9af8-00144feabdc0> [Accessed 3 September 2018].

Malthus, T. R., 2008. *An essay on the principle of population*. New York: Oxford University Press.

Mares, D. R., 2010. *Resource nationalism and energy security in Latin America: Implications for global oil supplies*. Houston, TX: Rice University.

Mahdavy, H. 1970 The patterns and problems of economic development in rentier states the case of Iran. In: Cook, M. A. ed. 1970. *Studies in the Economic History of the Middle East, London: Oxford University Press*. 428–467.

Markowitz, H. M., 1952. Portfolio selection. *Journal of Finance*, 7(1), 77–91.

Marshall, A., 1920. *Principles of economics*. London: Macmillan.

Matti, Stephanie., 2010. Resources and rent seeking in the Democratic Republic of the Congo, *Third World Quarterly,* 31(3), 401–413.

Maurice, C. and Smithson, C. W., 1984. The *doomsday myth: 10,000 years of economic crises*. Stanford, CA: Hoover Institution Press.

McCann, P., 2009. Location theory. In: Rowe, J. ed. 2009. *Theories of local economic development – linking theory to practice*. Farnham: Ashgate. 127–144.

McIntyre, L. J., 1999. *The practical skeptic: core concepts in sociology*. Mountain View, CA: Mayfield Publishing.

Meadows, D. H. Meadows D. L. Randers, J. and Behrens III, W.W., 1972. *Limits to Growth*. New York, NY: Potomac Associates.

Mehlum, H. Moene, K. and Torvik, R., 2006. Institutions and the resource curse. *Economic Journal*, 116(January), 1–20.

Melitz, M. J., 2003. The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica,* 71(61), 1695–1725.

Melitz, M. J., and Redding, S. J., 2012. *Heterogenous firms and trade*. National Bureau of Economic Research Working Paper 18652. [online] Available at: <http://www.princeton.edu/~reddings/papers/NBERw18652.pdf> [Accessed 2 June 2016].

Meissner, H. 2010., *The resource curse and rentier states in the Caspian region: a need for context analysis*. GIGA Working Paper No. 133. [online] Available at: <https://www.giga-hamburg.de/de/system/files/publications/wp133_meissner.pdf> [Accessed 23 May 2019].

Merriam, S., 2009. *Qualitative research: a guide to design and implementation. Revised and expanded from qualitative research and case study applications in education*. San Francisco, CA: John Wiley & Sons.

Metal Bulletin, 2007. Huayou looks for listing before Beijing Olympics. *Metal Bulletin*, [online] 9 May. Available at: <https://www.metalbulletin.com/Article/1415535/Search-results/Huayou-looks-for-listing-before-Beijing-Olympics.html> [Accessed 28 August 2018].

METI, 2009. Announcement of "strategy for ensuring stable supplies of rare metals". [online] Available at: <http://www.meti.go.jp/english/press/data/20090728_01.html> [Accessed 5 November 2015].

Mikesell, R. F., 1971. Conflict in foreign investor-host country relations: A preliminary analysis. In Mikesell, R. F. ed. *Foreign investment in the petroleum and mineral industries*. Baltimore, MD: Johns Hopkins Press, 29–55.

Moran, T. H., 1992. Mining companies, economic nationalism, and third world development in the 1990s. In: Tilton, J. E. ed. 1992. *Mineral wealth and economic development*. Washington DC: Resources for the Future. 19–38.

Moss, R. L. Tzimas, E. Kara, H. Willis, P. and Kooroshy, J., 2011. *Critical metals in strategic energy technologies - assessing rare metals as supply-chain bottlenecks in low-carbon energy technologies*. JRC Scientific and Technical Report. [online] Available at: <http://setis.ec.europa.eu/newsroom-items-folder/jrc-report-on-criticalmetals-in-strategic-energy-technologies> [Accessed 5 November 2015].

Mudd, G. M. Weng, Z. Jowitt, S. M. Turnbull, I. D. Graedel, T. E., 2013. Quantifying the recoverable resources of by-product metals: the case of cobalt. *Ore Geology Reviews*, 55, 87–98.

Munalula, Mulonda. and Matildah, Kaliba., 2016. Chinese foreign direct investment in Africa's natural resources and the impacts on local communities (a focus on extractive industries): review of literature. *World Journal of Social Sciences and Humanities*, 2(3), 102–108.

Murphy, J. and Schindler, S., 2009. Globalising development in Bolivia? Alternative networks and value-capture challenges in the wood products industry. *Journal of Economic Geography*, 11(1), 61–75.

Murshed, Syed. 2018. *The resource curse*. Newcastle Upon Tyne, UK: Agenda Publishing.

Nagurney, Anna., 2006. *Supply chain network economics: dynamics of prices, flows and profits*. Cheltenham: Edward Elgar.

Nassar, N. T. Barr, Rachel. Browning, Matthew. Diao, Zhouwei. Friedlander, Elizabeth. Harper, E. M. Henly, Claire. Kavlak, Goskin. Kwatra, Sameer. Jun, Christine. Warren, Simon. Yang, Man-Yu. and Graedel, T. E., 2012. Criticality of the geological copper family. *Environmental Science and Technology*, 46(2), 1071–1078.

Nassar, N. T. Du, Xiaoyue. and Graedel, T. E., 2015. Criticality of the rare earth elements. Journal of Industrial Ecology, 19(6), 1044–1054.

National Materials Advisory Board (NMAB), 1981. *Assessment of selected material issues*. Washington DC: National Academy Press.

National Research Council (NRC), 2008. *Minerals, critical minerals, on the U.S. economy*. Washington DC: The National Academies Press.

Natural Resource Governance Institute, 2017. *State-Owned Companies*. [online] Available at: <http://resourcegovernance.org/resource-governance-index/report/state-owned-companies> [Accessed 25 September 2017].

National Resource Governance Institute, 2017. *Sicomines deal offers four clear resource-for-infrastructure lessons*. [online] Available at: < https://resourcegovernance.org/blog/sicomines-deal-offers-four-clear-resource-infrastructure-lessons> [Accessed 3 September 2018]

Neal, Z., 2012. The *connected city: how networks are shaping the modern metropolis*. New York, NY: Routledge.

Nordbrand, Sara. and Bolme, Petter., 2007. *Powering the mobile world. Cobalt production for batteries in the DR Congo and Zambia*. [online] Available at: <http://germanwatch.org/corp/it-cob.pdf> [Accessed 29 April 2016].

Norrman, A. and Jansson, U., 2004. Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution and Logistics Management*, 34(5), 434–456.

North, D. 1990. *Institutions, institutional change, and economic performance*. New York, NY: Norton.

NREL, 2016. NREL Analysis: reimagining what's possible for clean energy. [online] Available at: <http://www.nrel.gov/continuum/analysis/manufacturing.html> [Accessed 14 July 2016].

Nuss, P. Harperm E.M. Nassar, N.T. Reck, B.K. and Graedel, T.E., 2014. Criticality of iron and its principal alloying elements. *Environmental Science and Technology*, 48(7), 4171–4177.

Oakdene Hollins, 2011. Study into the feasibility of protecting and removing critical raw materials through infrastructure development in the south east of England. [online] Available at: <http://cdn.awsripple.com/www.criticalrawmaterials.eu/uploads/EPOW-recovering-critical-raw-materials-combined.pdf> [Accessed 19 March 2014].

Ohlin, B., 1991. The theory of trade. In: Flam, H. and Flanders, M.J. eds. 1991. *Heckscher-Ohlin trade theory*. Cambridge, MA: The MIT Press. 39–69.

Onstad, E., 2017. Apple leads way in tracing cobalt from Congo, Microsoft lags – Amnesty. *Reuters*, [online] 15 November. Available at: <https://uk.reuters.com/article/uk-metals-cobalt-amnesty/apple-leads-way-in-tracing-cobalt-from-congo-microsoft-lags-amnesty-idUKKBN1DF04F> [Accessed 28 August 2018]

Opdenakker, R., 2006. Advantages and disadvantages of four interview techniques in qualitative research. *Forum Qualitative Social Research*, 7(4), Art. 11.

Ostrowski, W., 2013. The political economy of global resources. In: Dannreuther, R. and Ostrowski, W. eds. 2013. *Global Resources*. London: Palgrave Macmillan. 98–115.

Ou, Shiqi. Lin, Zhenhing. Wu, Zhixin. Zheng. Jihu. Lyu, Renzhi. Przesmitzki, Steven. and He, Zin. 2017. *A study of China's explosive growth in the plug-in electric vehicle market*. Oak Ridge National Laboratory. [online] Available at: <https://info.ornl.gov/sites/publications/files/Pub72210.pdf> [Accessed 17 July 2018]

Overland, Indra. 2019. The geopolitics of renewable energy: Debunking four emerging myths. Energy Research & Social Science, 49(March). 36–40.

Parker, Martin., 2000. *Organizational Culture and Identity, Unity and Division at Work*. London: Sage.
Paulette, L. Mahutga, M. and de Leeuw, J., 2009. Looking back and forging ahead: thirty years of social network research on the world-system. *Journal of World-System Research*, 15(1), 48–85.

Parker, Dominic P. and Vadheim, Bryan. 2017. Resource cursed or policy cursed? US regulation of conflict minerals and violence in the Congo. *Journal of the Association of Environmental and Resource Economists*, 4(1), 1–49.

PBL, 2011. *Scarcity in a sea of plenty? Global resource scarcities and policies in the European Union and the Netherlands*. [online] Available at: <http://www.pbl.nl/sites/default/files/cms/publicaties/500167001_0.pdf> [Accessed 19 March 2014].

Peck, H., 2006. Reconciling supply chain vulnerability, risk and supply chain management. *International Journal of Logistics Research and Applications*, 9(2), 127–142.

Peng, M. Bruton, G. Stan, C. and Huang, Y., 2016. Theories of the (state-owned) firm. *Asia Pacific journal of management*, 33(2), 293–317.

Pereira dos Santos, R.S. and Milanez, Bruno., 2015. The global production network for iron ore: materiality, corporate strategies, and social contestation in Brazil. *The Extractive Industries and Society*, 2(4), 756–765.

Peyer, Chantal., 2011. *How a company exploits a country. The case of Glencore in the Democratic Republic of Congo*. Available at: <http://www.bench-marks.org.za/research/drc_study_english_edition_6.pdf> [Accessed 29 April 2016].

Phelps, N. A. and Wood, A., 2006. Lost in translation? Local interests, global actors and inward investment regimes. *Journal of Economic Geography*, 6(4), 493–515.

Pinchot, G., 1967. *The fight for conservation*. Seattle, WA: University of Washington Press.

Pinsonneault, A. and Kraemer, K. L., 1993. Survey research methodology in management information systems: an assessment. *Journal of Management Information Systems*, 10(2), 75–105.

Pfleger, P. Lichtblau, K. Bardt, H. and Reller, A., 2009. *Rohstoffsituation Bayern: Keine Zukunft ohne Rohstoffe*. [online] Available at: <http://www.nachhaltigwirtschaften.at/e2050/e2050_pdf/reports/20110714_rohstoffsituation_bayern.pdf> [Accessed 19 March 2014].

Porter, M., 1994. The role of location in competition. *Journal of economics and business*, 1(1), 35–39.

Pryke, Sam., 2017. Explaining resource nationalism. *Global Policy*, 8(4), 474–482.

Punch, K., 1998. *Introduction to social research: quantitative and qualitative approaches*. London: Sage.

Raikes, Philip. Friis Jensen, Michael. and Ponte, Stefano., 2000. Global commodity chain analysis and the French filière approach: comparison and critique. *Economy and Society*, 29(3), 390–417.

Rao, Shashank. and Goldsby, Thomas. J. 2009. Supply chain risks: a review and typology. *International Journal of Logistics Management*, 20(1), 97–123.

Ravindran, A. Ravi. Bilsel, R. Ufuk. Wadhwa, Vijay. and Tao. Yang., 2010. Risk adjusted multicriteria supplier selection models with applications. *International journal of production research*, 48(2), 405–424.

Redding, S., 2008. *Economic geography: a review of the theoretical and empirical literature*. Centre for Economic Performance, LSE, CEP Discussion Papers. [online] Available at: <https://ideas.repec.org/p/cep/cepdps/dp0904.html?> [Accessed 14 October 2016].

Reichardt, J. and White, D., 2007. Role models for complex networks. The European Physical Journal B, 60(2), 212–214.

Regeringskansliet, 2013. *Sweden's minerals strategy for sustainable use of Sweden's mineral resources that creates growth throughout the country*. [online] Available at: <http://www.government.se/content/1/c6/21/89/86/30eccfae.pdf> [Accessed 19 March 2014].

ESRC., 2019. *Research Ethics Guidebook*. [online] Available at: <http://www.ethicsguidebook.ac.uk/> [Accessed 24th June 2019]

Resnick Institute, 2011. *Critical materials for sustainable energy applications*. [online] Available at: <http://resnick.caltech.edu/docs/R_Critical.pdf> [Accessed 5 November 2015].

Reuters, 2018a. POSCO to set up battery materials JVs with China's Zhejiang Huayou Cobalt. *Reuters*, [online] 24 January. Available at: <https://www.reuters.com/article/us-posco-china/posco-to-set-up-battery-materials-jvs-with-chinas-zhejiang-huayou-cobalt-idUSKBN1FD0E7> [Accessed 28 August 2018]

Reuters, 2018b. South Korea's LG Chem to set up battery material JVs with China's Zhejiang Huayou Cobalt. *Reuters,* [online] 24 April. Available at: < https://uk.reuters.com/article/uk-lg-chem-china/south-koreas-lg-chem-to-set-up-battery-material-jvs-with-chinas-zhejiang-huayou-cobalt-idUKKBN1HI04G> [Accessed 28 August 2018]

Ricardo, D., 2004. *The Principles of Political Economy and Taxation*. New York, NY: Dover Publications.

Ritchie, B. and Brindley, C., 2007. Supply chain risk management and performance: a guiding framework for future development. *International Journal of Operations and Production Management*, 27(3), 303–322.

Riddle, Matthew. Macal, Charles. M. Conzelmann, Guenter. Combs, Todd. E. Bauer, Diana. and Fields, Fletcher., 2015. Global critical materials markets: an agent-based modelling approach. *Resources Policy,* 45(September), 307–321.

Ritzema, F. 2015. Large SRB cobalt purchase brings hopes of price stability. *Metal Bulletin*, 24 November. [online] Available at: < https://www.metalbulletin.com/Article/3508728/Large-SRB-cobalt-purchase-brings-hopes-of-price-stability.html> [Accessed 28 August 2018]

Rodrik, D. 2016. Premature deindustrialisation". Journal of Economic Geography, 21(1), 1–32.

Roskill Information Services (Roskill)., 1979. *The economics of cobalt. 3rd edition.* London: Roskill.

Roskill Information Services (Roskill)., 2004. *The economics of cobalt. 10th edition.* London: Roskill.

Roskill Information Services (Roskill)., 2007. *The economics of cobalt. 11th edition.* London: Roskill.

Roskill Information Services (Roskill)., 2014. *Cobalt: Market Outlook to 2018*. London: Roskill.

Roskill Information Services (Roskill)., 2016. *January 2016 Cobalt Quarterly Review*. London: Roskill.

Roskill Information Services (Roskill)., 2016b. *Rare Earths: Global Industry, Markets & Outlook*. London: Roskill.

Roskill Information Services (Roskill)., 2017. *Antimony: World market for Antimony to 2025*. London: Roskill.

Roskill Information Services (Roskill)., 2017a. *Chromium: Global Industry, Markets & Outlook*. London: Roskill.

Roskill Information Services (Roskill)., 2017b. *Niobium: Global Industry, Markets & Outlook*. London: Roskill.

Roskill Information Services (Roskill)., 2017c. Tungsten: Global Industry, Markets & Outlook. London: Roskill.

Roskill Information Services (Roskill)., 2018. Cobalt: Global Industry, Markets & Outlook. London: Roskill.

Ross, Aaron. 2015. China's 'infrastructure for minerals' deal gets reality-check in Congo. *Reuters,* 8 July. [online] Available at: <https://www.reuters.com/article/congodemocratic-mining-china/insight-chinas-infrastructure-for-minerals-deal-gets-reality-check-in-congo-idUSL8N0ZN2QZ20150708> [Accessed 14 July 2018].

Ross, M., 1999. The political economy of the resource curse. *World Politics*, 51(2), 297–322.

Ross, M., 2001. Does oil hinder democracy? World Politics, 53(3), 325–361.

Ross, M., 2012. *The oil curse: how petroleum wealth shapes the development of nations*. Princeton, NJ: Princeton University Press.

Royal Society (Great Britain)., 1992. *Risk: Analysis, Perception and Management*. London: Royal Society.

Ruiz-Torres, Alex. J. and Mahmoodi, Farzad., 2007. The optimal number of suppliers considering the costs of individual supplier failures. *Omega*, 35(1), 104–115.

Rutherford, T. Murray, G. Almond, P. and Pelard M., 2018. State accumulation projects and inward investment regimes strategies. *Regional Studies*, 52(4): 572–584.

Sachs, J. and Warner, A., 1995. *Natural resource abundance and economic growth*. Development Discussion Paper 517a. Cambridge, MA: Harvard Institute for International Development.

Salant, P. and Dillman, D. A., 1994. *How to conduct your own survey*. New York, NY: John Wiley and Sons.

Samset, Ingrid., 2002. Conflict of interests or interests in conflict? diamonds & war in the DRC. *Review of African Political Economy* 29(93-94), 463–480

Saunders, M. Lewis, P. and Thornhill, A., 2012. *Research Methods for Business Students, 6th edition*. Harlow: Pearson Education Limited

Sauvant, Karl. and Chen, Victor., 2014. China's regulatory framework for outward foreign direct investment. *China Economic Journal*, 7(1), 141–163.

Sayer, A., 2000. *Realism and social science*. London: SAGE Publications.

Scheele, F. de Haan, E. and Kiezebrink, Vincent., 2016. *Cobalt blues. Environmental pollution and human rights violations in Katanga's copper and cobalt mines*. Amsterdam: Stichting Onderzoek Multinationale Ondernemingen (SOMO).

Schulz, K.J. DeYoung, J. H. Jr. Seal, R.R. II. and Bradley, D.C. 2017. *Critical mineral resources of the United States - economic and environmental geology and prospects for future supply.* U.S. Geological Survey Professional Paper 1802. [online] Available at: <https://pubs.er.usgs.gov/publication/pp1802> [Accessed 24 May 2019].

Schwarz, R., 2008. From rentier state to failed state: war and the de-formation of the state in Iraq. *A contrario*, 2008/1(5), 102–113.

Schwartz, P. and Gibb, B., 1999. *When good companies do bad things*. New York, NY: Wiley.

Shah, Fayaz. Ali. Yusaff, Rosman. Hussain, Altaf. and Hussain, Jawad., 2012. A critical review of multinational companies, their structures and strategies and their link with international human resource management. *Journal of business and management*, 3(5), 28–33.

Shepherd, B., 2012. *The gravity model of international trade: a user guide*. Thailand: United Nations.

Shim, Sang-Hyung., 2011. *China's rise and "Go Out" policy*. POSRI China Quarterly. [online] Available at: <https://www.posri.re.kr/files/file_pdf/82/14070/82_14070_file_pdf_1464069587.pdf> [Accessed 14 July 2018].

Shu, Tong. Chen, Shou. Lai, Kin Keung. Zhang, Xizheng. and Wang, Shouyang., 2014. *Managing risk of supply chain disruptions*. Oxford, UK: Routledge.

Shuy, R., 2003. In-person versus telephone interviewing. In: Holstein J.A., Gubrium, J. eds. *Inside Interviewing: New Lenses, New Concerns*. Thousand Oaks, CA: Sage. 175–193.

Yao, Shujie. Sutherland, Dylan. and Chen, Jian., 2010. China's outward FDI and resource-seeking strategy: a case study on Chinalco and Rio Tinto. *Asia-Pacific Journal of Accounting & Economics*, 17(3), 313–326.

Simons, R. L., 1999. How risky is your company? *Harvard Business Review*, 77(3), 85–95.

Simpson, D. Tomean, M. A. and Ayres, R., 2004. *Scarcity and growth in the new millennium: summary*. Resources for the Future. [online] Available at: <www.rff.org/documents/rff-DP-04-01.pdf> [Accessed 14 October 2014].

Sitkin, S.B., and Pablo, A.L. 1992. Reconceptualizing the determinants of risk behavior. *Academy of Management Review*, 17(1), 9–38.

Skirrow, R. G. Huston, D. L. Mernagh, T. P. Thorne, J. P. Dulfer, H. Senior, A. B., 2013. *Critical commodities for a high-tech world: Australia's potential to supply global demand*. Canberra: Geoscience Australia.

Smallman, C., 1996. Risk and organisational behaviour: a research model. *Disaster Prevention and Management*, 5(2), 12–26.

Šmihula, D., 2009. The waves of the technological innovations of the modern age and the present crisis. *Studia politica Slovaca* ,1(2), 32–47.

Smith, A., 1985. *The wealth of nations*. Bungay: The Chaucer Press.

Smith, H., 1975. *Strategies of social research: methodological imagination*. London: Prentice Hall International.

Smith, V. K. ed. 1979. *Scarcity and growth reconsidered*. Baltimore, MD: Johns Hopkins University Press.

Soubbotina, Tatyana, P. and Sheram, Katherine. A. 2000. *Beyond economic growth – meeting the challenges of global development*. Washington DC: World Bank.

Spekman, R. E. and Davis, E.W., 2004. Risky business: expanding the discussion on risk and the extended enterprise. *International Journal of Physical Distribution & Materials Management*, 34(5), 414–433.

Speirs, J. Houari, Y. and Gross, R., 2013. *Materials availability: comparison of material criticality studies, methodologies and results*. Working Paper III. UKERC/WP/TPA/2013/002. London: UK Energy Research Centre.

Spring, Jake. 2018. Hands off Brazil's niobium: Bolsonaro sees China as threat to utopian vision. [online] Available at: <https://www.reuters.com/article/us-brazil-election-china-niobium/hands-off-brazils-niobium-bolsonaro-sees-china-as-threat-to-utopian-vision-idUSKCN1MZ1JN> [Accessed 8 March 2020].

State Council, 2011. *12th Five-Year Plan on Industrial Reform and Upgrading*. Beijing: State Council. [online] Available at: <http://www.gov.cn/zwgk/2012-01/18/content_2047619.htm> [Accessed 14 July 2018].

Statistics Netherlands, 2010. *Critical materials in the Dutch economy – preliminary results*. [online] Available at: <http://www.cbs.nl/NR/rdonlyres/37ADC207-2FD4-4D34-B5DE-02A3ADBDF3B4/0/criticalmaterialsinthedutcheconomy.pdf> [Accessed 5 November 2015].

Stiglitz, J., 1974. Growth with exhaustible natural resources: efficient and optimal growth paths. *Review of Economic Studies*, 41, 123–137.

Stoop, Nik., Verpoorten, Marijke., and van der Windt, Peter. 2018. More legislation, more violence? The impact of Dodd-Frank in the DRC. PLoS ONE 13(8): e0201783. ttps://doi.org/10.1371/journal.pone.0201783.

Sturgeon, Timothy. J., 2009. From commodity chains to value chains: interdisciplinary theory building in an age of globalisation. In: Bair, Jennifer. ed. 2009. *Frontiers of commodity chain research*. Stanford, CA: Stanford University Press. 110–335.

Sturges, J. Hanrahan, K., 2004. Comparing telephone and face-to-face qualitative interviewing: a research note. *Qualitative Research*, 4(1), 107–118.

Sunley, P., 2008. Relational economic geography: a partial understanding or a new paradigm? *Economic Geography*, 81(1), 1–26.

Swartz, B., and Donegan, S., and Amoz, S., 2009. *Processing considerations for cobalt recovery from Congolese copperbelt ores*. Hydrometallurgy Conference 2009, The Southern African Institute of Mining and Metallurgy, 2009. [online]. <http://www.saimm.co.za/Conferences/Hydro2009/385-400_Swartz.pdf> [Accessed 28 January 2018].

Tang, C. S., 2006. Perspectives in supply chain risk management. *International Journal of Production Economics*, 103(2), 451–488.

Tahvonen, O., 2000. *Economic sustainability and scarcity of natural resources: a brief historical review*. Resources for the Future Issue Brief. [online] Available at: <http://www.rff.org/rff/Documents/RFF-IB-00-tahvonen.pdf> [Accessed 13 October 2014].

Tesla, 2016. *Tesla Gigafactory*. [online] Available at: <https://www.tesla.com/en_GB/gigafactory> [Accessed 14 July 2016].

The American Enterprise Institute and The Heritage Foundation, 2019. [online] Available at: <http://www.aei.org/china-global-investment-tracker/> [Accessed 29 May 2019].

The Economist. 1977. The Dutch Disease. *The Economis*t, 26 November. 1977. 82–83

The Economist, 2017. The death of the internal combustion engine. *The Economis*t, 12 August. [online] Available at: <https://www.economist.com/news/leaders/21726071-it-had-good-run-end-sight-machine-changed-world-death> [Accessed 21 August 2017].

Thompson, Michael. and Rayner, Steve., 1998. Risk and governance part I: the discourses of climate change. *Government and Opposition*, 33(2), 139–166.

Thun, Jörn-Henrik. and Hoenig, Daniel., 2011. An empirical analysis of supply chain risk management in the German automotive industry. *International journal of production economics*, 131(1), 242–249.

Tilton, J. E., 1996. Exhaustible resources and sustainable development. *Resource Policy*, 22(1/2), 91–97.

Tilton, J. E., 2006. Depletion and the long-run availability of mineral commodities. In: Doggett, M. E., and Parry, J. R. eds. 2006. *Wealth creation in the minerals industry: integrating science, business and education*. Colorado: Society of Economic Geologists. 61–70.

Tilton, J. E. and Lagos, G., 2007. Assessing the long-run availability of copper. *Resources Policy*, 32(3), 19–23.

Tinbergen, J., 1962. *Shaping the world economy: suggestions for an international economic policy*. New York, NY: The Twentieth Century Fund.

Torvik, R. 2002. Natural resources, rent seeking and welfare. Journal of Development Economics, 67(2), 455–70.

Trkman, Peter. and McCormack, Kevin., 2009. Supply chain risk in turbulent environments - a conceptual model for managing supply chain network risk. *International Journal of Production Economics*, 119(2), 247–258.

Tsai, Ming-Chih. Liao, Chun-Hua. and Han, Chia-shing., 2008. Risk perception on logistics outsourcing of retail chains: model development and empirical verification in Taiwan. *Supply chain management: an international journal,* 13(6), 415–424.

Tsurukawa, Nicolas. Prakash, Siddharth. and Manhart, Andreas., 2011. *Social impacts of artisanal cobalt mining in Katanga, Democratic Republic of Congo*. [online] Available at: <http://www.oeko.de/oekodoc/1294/2011-419-en.pdf> [Accessed 29 April 2016].

UK Government., 2019. *Data Protection*. [online] Available at: <https://www.gov.uk/data-protection> [Accessed 27 May 2019]

United Nations Conference on Trade and Development (UNCTAD), 2013. *World investment report 2013, global value chains: investment and trade for development*. New York, NY: United Nations.

United Nations Educational, Scientific and Cultural Organization (UNESCO), 2001. *MOST Annual Report 2001*. [online] Available at: http://www.unesco.org/most/most_ar_part1c.pdf [Accessed 9 December 2015].

US Congressional Budget Office, 1983. *Strategic critical nonfuel minerals: problems and policy alternatives*. [online] Available at: <http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/50xx/doc5043/doc15-entire.pdf> [Accessed 14 October 2014].

US Department of Defense (DOD), 2013. *Strategic and critical materials, 2013 report on stockpile requirements*. Washington DC: Office of the Under Secretary of Defense.

US Department of Defense (DOD), 2015. *Strategic and critical materials, 2015 report on stockpile requirements*. Washington DC: Office of the Under Secretary of Defense.

US Department of Energy (DOE), 2010. *Critical materials strategy*. Washington DC: DOE.

United States Geological Survey (USGS), 2005. *Cobalt*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/cobalmcs05.pdf> [Accessed 26 September 2016].

United States Geological Survey (USGS), 2011. *Cobalt.* [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2011-cobal.pdf> [Accessed 18 January 2016].

United States Geological Survey (USGS), 2012. *Cobalt*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2012-cobal.pdf> [Accessed 18 January 2016].

United States Geological Survey (USGS), 2012b. *Germanium*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/germanium/mcs-2012-germa.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2013. *Cobalt*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2013-cobal.pdf> [Accessed 18 January 2016].

United States Geological Survey (USGS), 2014. *Cobalt*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2014-cobal.pdf> [Accessed 18 January 2016].

United States Geological Survey (USGS), 2015. *Cobalt*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2015-cobal.pdf> [Accessed 18 January 2016].

United States Geological Survey (USGS), 2015. *The Mineral Industry of Congo (Kinshasa)*. [online] Available at: < https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/myb3-2015-congo-kinshasha.pdf> [Accessed 13 December 2019].

United States Geological Survey (USGS), 2016. *Antim*ony. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/antimony/mcs-2016-antim.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016a. *Beryllium*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/beryllium/mcs-2016-beryl.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016b. *Chromium*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/chromium/mcs-2016-chrom.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016c. *Cobalt*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2016-cobal.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016d. *Fluorspar*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/fluorspar/mcs-2016-fluor.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016e. *Gallium*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/gallium/mcs-2016-galli.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016f. *Graphite (Natural)*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/graphite/mcs-2016-graph.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016g. *Indium*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/indium/mcs-2016-indiu.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS). 2016h, *Magnesium Compounds*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mcs-2016-mgcom.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016i. *Niobium*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/niobium/mcs-2016-niobi.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016j. *Silicon*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/silicon/mcs-2016-simet.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016k. *Tungsten*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/tungsten/mcs-2016-tungs.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2016l. *Rare Earths*. [online] Available at: <http://minerals.usgs.gov/minerals/pubs/commodity/silicon/mcs-2016-simet.pdf> [Accessed 18 July 2016].

United States Geological Survey (USGS), 2018. *Cobalt*. [online] Available at: < https://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2018-cobal.pdf> [Accessed 5 September 2018].

Vahabi, Mehrdad., 2017. A critical survey of the resource curse literature through the appropriability lens. CEPN No 2014-14. [online] Available at: <https://hal.archives-ouvertes.fr/hal-01583559/document> [Accessed 13 December 2019].

Vernon, R., 1971. *Sovereignty at bay: the multinational spread of US enterprises*. New York, NY: Basic Books.

Wagner, Stephan M. and Bode, Christoph., 2008. An empirical examination of supply chain performance along several dimensions of risk. *Journal of business logistics*, 29(1), 307–325.

Wang, Pan. and Yu, Zhihong., 2014. China's outward foreign direct investment: the role of natural resources and technology. *Economic and political studies*, 2(2), 89–120.

Walker, R. A. 1979., Human-environment relations, editor's introduction. *Antipode*, 11(2), 1–16.

Wallerstein, I., 1974. *The modern world system*. New York, NY: Academic Press.

Wallerstein, I. 2000., Introduction to the special issue on commodity chains in the world economy. *Review*, 23(1), 1–13.

Williamson, O. E., 1985. *The economic institutions of capitalism*. New York, NY: Free Press.

World Bank, 2015. *Total natural resources rents (% of GDP)*. [online] Available at: <http://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS> [Accessed 10 July 2016].

World Health Organization (WHO), 2006. *Cobalt and inorganic cobalt compounds: concise international chemical assessment document 69*. [online] Available at: <http://www.who.int/ipcs/publications/cicad/cicad69%20.pdf> [Accessed 29 April 2016].

World Trade Organisation (WTO), 2016. *International Trade Statistics 2016*. [online] Available at: <https://www.wto.org/english/res_e/statis_e/its2015_e/its2015_e.pdf> [Accessed 10 July 2016].

Wu, Desheng. Dash. and Olson, David., 2010. Enterprise risk management: a DEA VaR approach in vendor selection. *International journal of production research*, 48(16), 4919–4932.

von Thünen, J., 1826. *Isolated state: An English edition of Der isolierte Staat*. Translated from German by Wartenberg, C. and Hall, P. 1966. Oxford: Pergamon Press.

Vorley, T. Mould, O. and Courtney, R., 2012. My networking is not working! Conceptualising the latent and dysfunctional dimensions of the network paradigm. *Economic Geography*, 88(1), 77–96.

Ward, H., 2009. *Resource nationalism and sustainable development: A primer and key issues*. London: International Institute for Environment and Development.

Weber, A., 1909. *Theory of the location of industries*. [e-book] Available at: <https://archive.org/stream/alfredweberstheo00webe/alfredweberstheo00webe_djvu.txt> [Accessed 5 August 2016].

Williamson, O., 1975. *Markets and hierarchies*. New York, NY: Free Press.

Williamson, O., 1985. *The economic institutions of capitalism*. New York, NY: Free Press.

Wilson, E. J. I., 1987. World politics and international energy markets. *International Organization*, 41(1), 125–149.

Wilson, J., 2015. Understanding resource nationalism: economic dynamics and political institutions. *Contemporary Politics*, 21(4), 399–416.

World Bank, 2019. *World Bank national accounts data, and OECD national accounts data files*. [online] Available at: <https://data.worldbank.org/indicator/ny.gdp.mktp.cd> [Accessed 6 May 2019].

Xanthopoulos, Anastasios. Vlachos, Dimitrios. and Iakovou, Eleftherios., 2012. Optimal newsvendor policies for dual-sourcing supply chains: a disruption risk management framework. *Computers & operations research*, 39(2), 350–357.

Yeung, H. W.-C., 2015 Regional development in the global economy: a dynamic perspective of strategic coupling creation in global production networks. *Regional Science: Policy & Practice*, 7(1), 1–23.

Yeung, Henry. Wai-Chung. and Coe, Neil. M., 2015. Toward a dynamic theory of global production networks. *Economic Geography*, 91(1), 29–58.

Yeomans, John., 2018. Miners launch bid to avert punishing new taxes in DRC. *The Telegraph*, 25 March. [online] Available at: < https://www.telegraph.co.uk/business/2018/03/25/miners-launch-bid-avert-punishing-new-taxes-drc/> [Accessed 16 July 2018].

Yin, R., 2009. *Case study research: design and methods*. 4th edition. Thousand Oaks, CA: Sage.

Yu, Haisheng. Zeng, Amy. Z. and Zhao, Lindu., 2009. Single or dual sourcing: decision-making in the presence of supply chain disruption risks. *Omega*, 37(4), 788–800.

Zalik, A., 2004. The Niger Delta: ‘petroviolence’ and ‘partnership development’. *Review of African Political Economy*, 31(101), 401–424.

Zeng, A. Z. Berger, P.D. and Gerstenfeld, A., 2005. Managing the supply-side risks in supply chains: taxonomies, processes and examples of decision-making modelling. In: Geunes, J. Akçali, E. Pardalos, P.M. Romeijn, H. E. Shen, Z-J. M. eds. 2005. *Applications of Supply Chain Management and E-Commerce Research*. Berlin: Springer. 141–160.

Zeuner, Brett. 2018. An obsolescing bargain in a rentier state: multinationals, artisanal miners, and cobalt in the Democratic Republic of Congo. *Frontiers in Energy Research*, https://doi.org/10.3389/fenrg.2018.00123.

Zhang, Yi., 2009. Unravelling the complex motivation behind China's FDI. Tjalling C. Koopmans Research Institute Discussion Paper Series 09-02. [online] Available at: <https://www.uu.nl/files/rebousedp200909-02pdf> [Accessed 27 May 2019].

70 signatories., 2014. An open letter: Dear governments, companies, non-governmental organisations, and other stakeholders implicated in efforts of various kinds related to the issue of 'conflict minerals'. [online]. Available at: < https://ethuin.files.wordpress.com/2014/09/09092014-open-letter-final-and-list.pdf> [Accessed 6 January 2020].